

# UNCLASSIFIED

AD NUMBER
AD820778
NEW LIMITATION CHANGE
TO Approved for public release, distribution unlimited
FROM Distribution authorized to U.S. Gov't. agencies only; Administrative/Operational Use; MAY 1967. Other requests shall be referred to U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
AUTHORITY
USAEWES Notice, 12 Apr 1983

THIS PAGE IS UNCLASSIFIED

AD820778

CONTRACT REPORT NO. 8-185

# MATERIALS FOR BEST CONTROL OF ROADS AND AIRFIELDS IN THE THEATER OF OPERATIONS

F. L. Rostler

W. D. Milton

C. A. Dallas



May 1967

Sponsored by

U. S. Army Materiel Command

Conducted for

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

Under

Contract No. DA-22-079-eng-483

by

Materials Research and Development Inc.

Orlando, California

Each transmission of this document outside the agencies of the U. S. Government must have prior approval of U. S. Army Engineer Waterways Experiment Station.

## FOREWORD

This report covers the work performed under Contract No. DA-22-079-eng-483, dated 29 April 1966, between the U.S. Army Engineer Waterways Experiment Station and Materials Research and Development, Inc. The research is sponsored by the U.S. Army Materiel Command under DA project 1-V-0-21701-A-04 "Trafficability and Mobility Research," Task-05. "Mobility Engineering Support (Dust Control, Southeast Asia) "

In accord with the original research proposal submitted 21 January 1966 and the Scope of Work defined in the subsequent executed research contract of 29 April 1966, the short-range objective comprises primarily the improvement of two types of dust control agents identified in the "Guide Manual for Selection and Use of Dust Palliatives and Soil Waterproofers in the Theater of Operations" (1). Two proprietary products, one called Product A (a bituminous material), and the other Product B (a petroleum resin), are mentioned in the above quoted manual as having certain capabilities as dust palliatives, but not being sufficiently effective to satisfy present requirements. It was the principal aim to develop at least one product formulation which could serve the objective of the project dealing with the present emergency which is to provide a suitable dust control material in support of military operations.

A report, "Dust Alleviators" (2) describes tests conducted by the U.S. Army Engineers (WES) on two compounds identified as proprietary products used as concrete curing agents, one a resin-base compound, the other a latex-base compound. Since this report pointed out some of the advantages of preparations providing a flexible film deposit on the surface of soils, latex-based systems were also explored in the present investigations.

Concurrently with experiments conducted under this contract, potential suppliers of raw materials and potential manufacturers of the preparations under development were contacted in order to make sure that the results of the study could be utilized on short notice to cope with the present emergency outlined in the briefing soliciting this research.

Project administrator for the Contractor was Mr. B. A. Vallerga, technical advisor and coordinator was Mr. G. R. Kozan of WES. Contracting Officers of the Corps of Engineers were Col. J. R. Oswalt, Jr., and Lt. Col. G. E. Jester.

## CONTENTS

FOREWORD . . . . .	iii
SUMMARY . . . . .	vii
ORGANIZATION OF REPORT . . . . .	ix
 PART ONE--RESIN SYSTEMS . . . . .	 1
Introduction . . . . .	1
Dust Palliatives Based on Petroleum Resins . . . . .	2
Definition of Approach . . . . .	2
Influence of Polymer Addition on Viscosity Characteristics of Liquid Petroleum Resins . . . . .	3
Effect of Polymer-Base Oil Combinations . . . . .	4
The Concept of Composite Emulsions . . . . .	8
Testing of Cementing Power . . . . .	9
Tests Carried Out at WES . . . . .	11
Selection of Main Ingredients for Resin System . . . . .	13
 PART TWO--LATEX SYSTEMS . . . . .	 16
Introduction . . . . .	16
Selection of Base Polymer . . . . .	16
Wind and Water Erosion Tests . . . . .	18
 PART THREE--BITUMINOUS MATERIALS . . . . .	 20
Introduction . . . . .	20
Base Bitumen . . . . .	21
Penetration of Bituminous Systems Into Soils . . . . .	21
 PART FOUR--RESULTS AND RECOMMENDATIONS . . . . .	 26
Introduction . . . . .	26
Resinous Systems . . . . .	26
Latex Systems . . . . .	27
Bituminous Materials . . . . .	28
General Recommendations . . . . .	28
 REFERENCES . . . . .	 30
 TABLES I THROUGH XXIX . . . . .	 32
 FIGURES 1 THROUGH 11 . . . . .	 66
 APPENDIX I--TABLES A-I THROUGH A-V and FIGURES A-1 THROUGH A-3 . . . . .	 73
 APPENDIX II--TEST METHODS and FIGURES A-4 THROUGH A-10 . . . . .	 81
 APPENDIX III--UNPUBLISHED REFERENCES . . . . .	 99

## SUMMARY

The present investigation had two objectives. One was the development of an effective multipurpose dust palliative suitable for immediate use at advanced military bases. The other had the long-range aim of exploring several agents and techniques for treating soils at various military installations for dust abatement and increased trafficability. One of the main requirements for the first objective was the compliance with the limitation that the maximum amount to be applied should not exceed 3 pounds of material per square yard. Effectiveness with various soil types, low cost and ease of application were other stipulations. This report details the work performed and describes the results obtained.

The primary short-range objective has been attained in that a product was developed which can be used in the present emergency and in compliance with the requirements of logistics, including the limitation of maximum amounts permissible. The product developed is a cationic emulsion of a solution of a thermoplastic polymer, a coumarone-indene resin, and a polar oil. The emulsion applied in the specified amount of 3 pounds per square yard provides effective protection against dust caused by air blasts as produced by aircraft, and against the effects of rain and of limited random traffic. Estimated product cost is within the range specified.

The long-range objective has been accomplished to the extent that several systems were shown to give products useful in combating dust and increasing trafficability. Resinous systems, latex systems and bituminous systems were explored. One potentially useful approach to the long-range objective is to combine products of the resinous emulsion type with bituminous products compounded as compatible emulsions. Such blends of emulsions permit treatments of soils for a variety of purposes utilizing the beneficial effects of both types of treating agents.

Some of the formulations developed under this contract are usable in the present form, some need improvement. The results of the investigation particularly suggest the desirability of further work aiming at the development of products of lower cost and at establishing the interdependence of amounts applied and effectiveness obtained.

## ORGANIZATION OF REPORT

This Summary Report submitted herewith has been organized in five parts. PART ONE constitutes the main effort and describes the work performed in the area of Group III type products (Resin Systems). PART TWO reports the work on Latex Systems. PART THREE deals with the portion of the work devoted to the development of a product of Group I type (Bituminous Materials). PART FOUR comprises the discussion of results and recommendations for their utilization. PART FIVE is the Appendix, describing the raw materials used and testing procedures.

## PART ONE--RESIN SYSTEMS

### Introduction

In view of the urgency of the project and the priorities of the objective defined in the meeting held at the Waterways Experiment Station, Vicksburg, Mississippi, on 24 January 1966, the main effort of the investigation was directed towards expansion of the knowledge of the functions of systems based on liquid petroleum resin in general, and specifically towards the improvement of known formulations based on this raw material which is abundantly available at relatively low cost.

The purpose of classifying the group of products explored in this part of the investigation as "Resin Systems" is for the sake of continuity of nomenclature, and not to establish whether or not a certain group of products, generally referred to as resins, have a categorical merit as dust proofing agents. It must be kept in mind that a great number of products which fall into the category of resins, such as phenolic resins, poly(ester) resins, and many others, have not been included in the present investigation. In the broadest meaning of the term, "Resin Systems", all products should be considered in this category which contain resins as the main ingredient.

The main characteristics of resins are that they are amorphous and do not possess the property of elastomers of being extensible and retractable. Many subdivisions of the class "Resins" can be made, such as natural and synthetic, thermoplastic and thermosetting, high melting and low melting, etc. The resin system used in the present investigation employs products which represent a relatively narrow group of resins, the main requirement being that the resins have such physical characteristics that they are soluble and fusible before application to soils and function as cementing agents after deposition on soils.

It appears appropriate for the sake of clarity to define the raw material "resin" as employed in the present investigation as "a liquid resinous petroleum material,

having a steep temperature-viscosity curve when plotted near the ambient temperature range." The conclusions made on the basis of the findings reported are thus limited to resins selected to be easily processed raw materials for the manufacture of dust control agents by means of dissolving or dispersing them in suitable carriers for deposition on soils.

#### Dust Palliatives Based on Petroleum Resins

The proprietary product identified in paper No. 4-756 (1) as Product B, compared with ordinary petroleum products such as neutral oils, drainings, etc., is one of the more sophisticated products of the class of liquid petroleum products used in the treatment of soils for dust abatement. This product has been described in the literature in considerable detail as to composition, function, application and field performance (3,4,5,6,7,8,9). The product has also been used on military installations for wind erosion control as documented in the literature (5,6,7). In view of the available background information, it was logical that Product B was singled out for the first approach to finding a suitable solution to the problem as defined in the objectives of the present project.

The main shortcomings of Product B, if to be used as a multi-purpose agent to control soil erosion caused by military aircraft as well as by natural forces such as wind and rain, are its limited cohesiveness and only moderate ability to penetrate fine grain soils. It was consequently the first endeavor in this phase of the investigation to find means of improving these two properties, by first reinforcing the petroleum resin constituting the principal component of Product B, and to improve the emulsification system to aid in penetration.

#### Definition of Approach

In line with the definition of the type of resins investigated in this project, the primary attack was to alter, by suitable additives, the viscosity-temperature characteristics of the petroleum resin base to obtain a product which is highly viscous at low temperature (e.g., ambient temperature) and highly fluid at elevated temperature. It was anticipated that a product having a stringy and gel-like consistency when deposited in the soil, but being sufficiently fluid at elevated temperature to be easily emulsifiable, would be a suitable base product to give the



desired improvement in cohesiveness. In order to retain the cohesiveness of the soil for an extended period of time after treatment, nonsetting (and noncuring) additives were believed to be preferable to additives which cause the preparation to harden with time. In order to improve the penetration characteristics a variety of emulsification systems were investigated as well as the employment of polar liquids in the solvent system.

#### Influence of Polymer Addition on Viscosity Characteristics of Liquid Petroleum Resins

The base petroleum resin used in this series of tests has the properties shown in Reference (3), column 3, as Example 1, as having the typical characteristics reported in Table A-I of Appendix I.

The particular resin used is produced by fractional distillation of a solvent extract from the refining of lubricating oils and is known under the trade name of Califlux GP. Similar products are available from a number of sources at low cost and are in ample supply.

The additives for this series of tests were selected to be representative of a great variety of polymers and polymer derivatives. The products tested, identified by chemical type and trade name, are listed in Table A-II of Appendix I.

In the first series of tests the polymers were added to the resin base in an amount of 3 percent by weight\*. Incorporation was accomplished by gradual addition of the polymers either in dry form or as latex, under stirring at 150-185°C. The equipment used was, for the preliminary investigation of the viscosity characteristics, a beaker mounted on a thermostatically controlled hot plate and an electric stirrer running at slow speed. In the later work, when large samples were produced employing latex as the source of polymer, the equipment consisted of a three-neck flask equipped with a reflux condenser, water separator, dropping funnel, variable speed stirrer, and an electric heating mantle controlled by a variable voltage transformer. Figure A-1 of Appendix I shows the assembly. In the final stages of the work, when dry polymers were used as additives, an Eppenbach Homomixer was used in place of the stirrer. This assembly is shown in Figure A-2 of Appendix I. Time of incorporation was 2 hours. All polymer types tested, except the NBR, PVC, and carboxylated SBR, gave homogeneous solutions by this method of incorporation.

\*Wherever %, or wt.%, is mentioned in this report, it denotes percent of the final product.

Some of the solutions were also heated for an additional 2 hours at 250°C. The purpose of the prolonged heating was to determine the degree of depolymerization of the polymers obtainable and the effect on the properties of the solution. Since the stoichiometric ratio of polymer to solvent is inversely proportional to the molecular weight, this test was considered important to determine whether mol percents or weight percents are important to accomplish desired changes in properties, including cementing power.

Attempts to produce a homogeneous solution of neoprene in the same base oil were unsuccessful. The reason for the incompatibility of the four polymers with this particular resin base are the saturated hydrocarbons present in the petroleum product. The four polymers were therefore set aside for later testing in fully unsaturated oils.

A second series of tests was then conducted by further diluting the solutions obtained in the petroleum resins containing about 90 percent unsaturates with a saturated hydrocarbon oil in a 1:1 ratio. A petroleum white oil, having a viscosity of 135 cP at 77°F, was used as this diluent. This second series of tests served two purposes. One was to determine the tolerance of the systems for saturated hydrocarbons which are poor solvents for polymers, the second to ascertain the degree of viscosity change in this system containing only 1.5 percent of polymers. The viscosities of the solutions were determined by ASTM Methods D445, D2170, and D2171.

The effects on viscosity are shown in Tables I and II. The viscosity characteristics of the base resin and of a higher viscosity petroleum resin of the same type are shown in Table I for comparison. The typical characteristics of this higher viscosity product, known under the proprietary name of Califlux 550, are shown in Table A-I of Appendix I for comparison with those of the base resin, Califlux GP. The effects on cementing power were investigated on treated soil specimens as described below.

#### Effect of Polymer-Base Oil Combinations

On the basis of the data presented in Tables I and II the following polymers were selected for testing their effects as cementing agents:

NR

Pliolite 5352 (a high molecular weight SBR)

Kraton 101 (a thermoplastic block polymer  
of SBR composition)

Pliopave L-165-K (a cationic SBR latex)

Vistanex MML-100 (a poly(isobutylene))

Goodyear X335 (a liquid SBR rubber)

The last polymer on this list was included for checking on the value of low molecular weight polymers.

The polymer solutions were emulsified by an anionic emulsification system similar to that used in Product B, which is a slightly anionic (mostly nonionic) emulsion of the base petroleum resin described earlier. The emulsification system consisted of a fatty acid soap (0.1 percent tall oil soap), and a nonionic surfactant (1.9 percent Oronite NI-W). Solids content of the emulsions was, as in Product B, 60 percent.

Details of the test procedure are given in Appendix II under Test Method 1--Soil Preparation for Tests of Wind and Water Erosion Resistance. Essentially the tests were as follows: The emulsions were applied at the rate of 3 pounds per square yard of concentrate, which was diluted with 4 volumes water before application. This gave a total amount of fluid of 2 gallons per square yard. The soil used in these tests was a dry, sandy soil (identified in Table A-III and Figure A-3 of Appendix I as Antioch sand). After the emulsion had penetrated the soil, the still moist soil was mixed with a spatula and then dried in an oven at 125°F for 18 hours. The dried soil was removed from the oven, remixed, and put back into the oven for an additional 2 hours. One portion of the specimen was tested noncompacted for wind resistance by Method 2A for wind resistance of uncompacted soil (see Appendix II).

Data obtained in determining wind resistance with the miniature wind machine described in Appendix II as Method 2A have been found to correlate with data obtained by Chapil in testing agricultural soils with a large portable wind tunnel designed for use in field testing (10\*,11,12\*).

A second portion of the dried, treated soil, also noncompacted, was subjected to simulated rainfall as described in Appendix II under Method 3A--Water Erosion of Noncompacted Soil. These tests were designed to measure the cementing

\*References 10 and 12, which are unpublished, are presented in Appendix III.

effect of the preparations as exhibited by retained cohesiveness imparted to the soil and revealed by "self-healing properties". Since the ability of Product B to retain cohesiveness over an extended period of time is one of the valuable features of this preparation, it was considered important to determine to what extent this property was influenced by polymer addition. The results of the tests, shown in Table III, were inconclusive regarding the reinforcing effect of the individual polymers but indicated that wind resistance is enhanced by low molecular weight polymers (compare sample 30 with 31, 34 with 35, and 37 with 34), and that water resistance was decreased by the presence of the strong anionic surfactant used in making the emulsions (compare sample 29 with 157 of Table IV). Depolymerization (lowering molecular weight) appears to have a detrimental effect on water resistance (compare 30 with 31, 34 with 35, and 37 with the other solutions).

The above reported findings suggested, in addition to the need for a change of the emulsification system, the necessity to explore other solvents of the unsaturated resinous type. It appeared particularly desirable to switch from the anionic-nonionic system to a cationic emulsification system and to find resinous solvents free of saturated hydrocarbons and of a more distinct polar nature.

The desirability of a cationic emulsification system was suggested by the need for a better bond of resins to soils and the required improvement in water resistance. A cationic emulsification system was believed most promising since cationic emulsions are known to plate-out more effectively on soils than anionic systems and to give deposits which are not re-emulsifiable. It was, however, realized that a small amount of a nonionic surfactant might be needed with some materials to increase ease of emulsification and emulsion stability.

As a result of screening tests of a great number of commercially available cationic surfactants, the following emulsification system was singled out as suitable for the purpose:

oil phase . . . . .	60%
water . . . . .	37%
Redicote E-1 . . . . .	2%
glacial acetic acid . . . . .	1%

The data shown in Table IV demonstrated the correctness of the concept involving the change of the emulsification system. Incidentally, it is also shown in this table that white oil, which is known not to be adsorbed on soils, has a detrimental effect on water resistance.

NR

Pliolite 5352 (a high molecular weight SBR)

Kraton 101 (a thermoplastic block polymer  
of SBR composition)

Pliopave L-165-K (a cationic SBR latex)

Vistanex MML-100 (a poly(isobutylene))

Goodyear X235 (a liquid SBR rubber)

The last polymer on this list was included for checking on the value of low molecular weight polymers.

The polymer solutions were emulsified by an anionic emulsification system similar to that used in Product B, which is a slightly anionic (mostly nonionic) emulsion of the base petroleum resin described earlier. The emulsification system consisted of a fatty acid soap (0.1 percent tall oil soap), and a nonionic surfactant (1.9 percent Oronite NI-W). Solids content of the emulsions was, as in Product B, 60 percent.

Details of the test procedure are given in Appendix II under Test Method 1--Soil Preparation for Tests of Wind and Water Erosion Resistance. Essentially the tests were as follows: The emulsions were applied at the rate of 3 pounds per square yard of concentrate, which was diluted with 4 volumes water before application. This gave a total amount of fluid of 2 gallons per square yard. The soil used in these tests was a dry, sandy soil (identified in Table A-III and Figure A-3 of Appendix I as Antioch sand). After the emulsion had penetrated the soil, the still moist soil was mixed with a spatula and then dried in an oven at 125°F for 18 hours. The dried soil was removed from the oven, remixed, and put back into the oven for an additional 2 hours. One portion of the specimen was tested noncompacted for wind resistance by Method 2A for wind resistance of uncompacted soil (see Appendix II).

Data obtained in determining wind resistance with the miniature wind machine described in Appendix II as Method 2A have been found to correlate with data obtained by Chepil in testing agricultural soils with a large portable wind tunnel designed for use in field testing (10\*, 11, 12\*).

A second portion of the dried, treated soil, also noncompacted, was subjected to simulated rainfall as described in Appendix II under Method 3A--Water Erosion of Noncompacted Soil. These tests were designed to measure the cementing

\*References 10 and 12, which are unpublished, are presented in Appendix III.

Types of commercially available unsaturated resinous solvents are actually limited in number. Hundreds of products known as rubber extender oils which fall in this category are available but the difference between them is primarily in their trade names. In order to check on interchangeability and to establish different sources of supply, samples of such extender oils were obtained from three suppliers, namely Golden Bear Oil Co., Phillips Petroleum Co., and Tidewater Oil Co.

Two samples of highly unsaturated resinous oils were obtained from Enjay. These latter products, known under the names "CTLA Polymer" and "RP220", respectively, are byproducts obtained in cracking processes. They are often described as "reactive polymers" or "polymerized dienes". Products of this type, known in the petroleum industry also as "Gray Tower residues", have been marketed by other suppliers under various designations, but being in great demand as rubber reclaiming oils and as core binding compounds used in foundries, they are, at the present, in short supply. It was however ascertained in discussions with Enjay that the products could be made available in large amounts if warranted by greatly expanded demand.

A third type product which is believed, on the basis of tests carried out in our laboratory in connection with another project, to be of considerable potential value as a polar solvent for polymers is a concentrate of higher molecular weight nitrogen bases obtained from gilsonite. This product, produced by American Gilsonite Company under the designation, GN-104, has therefore been selected for future tests in the present project, particularly since the product is available in large amounts at relatively low cost. The resinous products mentioned above are described in Table A-IV of Appendix I.

Observation of the rheological properties exhibited by the solutions reported in Table II suggested including among the base oils, also some high boiling petroleum products which contain a substantial amount of saturated hydrocarbons. A lubricating oil distillate identified in Table A-IV of Appendix I as "SR Stock" and a petroleum white oil (identified in the same table as White Oil 350 SSU at 100°F) were therefore added to the list of products to be used as base oils. It was felt intuitively that the gelling effect of this type of oils on polymer solutions might offer possibilities of considerable consequence for this project. That this intuition was correct is shown later in this report discussing experiments under the heading, "Composite Emulsions".

The experiments described above should be considered primarily qualitative orientation studies aimed at selection of ingredients for quantitative studies to follow. In preparation for this future work, 36 cationic emulsions employing the emulsification system selected were prepared to comprise a wide variety of compositions differing in base oil, polymer type and polymer concentrations. The emulsions and their compositions are identified in Table V by composition of oil phase. The emulsification system and water content were the same in all cases. The compositions tested comprise a greater variety, not only in base oils but also in polymers, than tested in the form of anionic emulsions reported in Table III.

#### The Concept of Composite Emulsions

In addition to the emulsions described in Table V, a series of samples was prepared by making blends of the emulsions. The second series provided additional preparations constituting a different and new type of compound which were labeled "Composite Emulsions". In Table VI are listed the blends made, the composition of the composite emulsions and the consistency of the solids (oil phase, free of water), as rated by handling with a spatula.

The concept of using composite emulsions might become, as mentioned earlier in this report, of considerable consequence in the field of soil treatment. This approach, comprising the mixing of separately prepared emulsions, makes it possible to apply to soils, ingredients which are not compatible and thus offers the possibility to form gels in situ as the emulsions break and the water leaves the system.

Because of the urgency of the project, as expressed by the priority of the objectives and the short time allotted for the pursuit of this contracted research, it was only possible to explore the value of composite emulsions in a cursory manner. It would require considerable additional study and exploration to reduce this concept to practice. Nevertheless, the possibility appears established of combining in emulsion form otherwise incompatible ingredients for deposition on soils. The main efforts to be expended in future exploration of this approach and in making it operative would be to select the most effective ingredients for the formation of strongly cohesive gels and to stabilize the system to achieve good storage stability. This latter requirement is given by the known facts that migration takes place between dispersed phase particles and that they have a tendency to interact, although separated from each other by the dispersing medium.

### Testing of Cementing Power

The cementing power of the preparations was tested by Methods 1A, 2A, and 3A, described in Appendix II, using basically the same procedures employed in testing the anionic emulsions, which results were reported in Table III, except that in some cases, higher dilutions than 1:4 were used. The rate of application was in all cases 3 pounds of concentrate per square yard. The depth of penetration obtained corresponded to the degree of dilution which resulted with the higher dilutions in deeper penetration and lower deposits of solids per unit of treated soil. The results obtained with these cationic emulsions are presented in Table VII.

The test results indicate that the resinous solvents of medium unsaturation, contained in samples 157, 158 and 160, give the desired "self-healing" effect in that the remixed treated soils show good weather and wind resistance, while the saturated solvents, as contained in sample 159, did not develop sufficient cohesiveness (see also samples 39 and 190 in Table IV). Sample 161 shows that this highly unsaturated solvent dried to a brittle binder which lost tack and cohesiveness and thus, the self-healing characteristic. All other emulsions gave soils with fairly good properties. The data also show (see particularly samples 168 to 173) that the effect of polymers is not necessarily contingent on the amounts of polymers present, above certain minimum percentages, which suggests that cost can be kept low by using small amounts of polymers. There also seems to be little difference between the NBR type polymers used and whether or not the polymer has been incorporated dry or in the form of latex. Of all the polymers compared the thermoplastic product and the NBR type appear most effective, the latter's effectiveness depending very much on the type of solvent used.

On the basis of test results recorded in Table VII and the appearance of the oil phase (see Table VI), emulsions were then compounded with the aim of combining the desirable features of the individual components. These compounded emulsions were then applied to the same sandy soil and tested for resistance to wind and water by Methods 1, 2 and 3. The data are reported in Table VIII.

A critical review of the data in Table VIII revealed that the most promising solvents to be explored further are Califlux GP (and similar materials, e.g. Philrich 5 and



Califlux 550), GN-104, CTLA and possibly the SR stock material. The data confirm that the best polymers for the purpose are the thermoplastic type polymers, such as Kraton 101, and the NBR polymers, such as Chemigum N-615 and Hycar 1441.

Blends of emulsions were then prepared and evaluated as shown in Table IX. The experiments proved that when making blends of emulsions, the properties are additive in that the selection of blends produced preparations which satisfied the requirements under the particular conditions of the tests used in Methods 2B and 3B. These two test methods differ from the methods of evaluation used in the preceding tests in that the soil was treated by a spray-on application and tested after drying without remixing. The test results are, therefore, not affected by the ability of the soil to be self-healing, but the results are indicative for which compositions can be expected to perform satisfactorily in a manner corresponding to the requirements set up by the Corps of Engineers as criteria in their testing procedures.

The test conditions used in the preceding tests served to narrow the group of products for further tests. More severe test conditions than used in this elimination procedure were then chosen for the test reported in Table X. The first three specimens listed represent the resinous solvents found most promising. The data show that the CTLA product imparts too much brittleness to the binder if used as a 50 percent replacement for the somewhat less unsaturated product GP. The two samples of GN-104, differing in amount of volatile fraction, showed that a less volatile product is preferable. Samples 249 and 253 show that the polymers Kraton 101 and Hycar 1441, used as additives to compatible resinous solvents, are effective reinforcing agents. Comparison of Samples 252 and 253 confirm the previous finding that increasing the amount of polymer does not always result in a corresponding improvement in quality of the binder. Samples 255 and 256 show that Califlux GP, the solvent of medium unsaturation, is a suitable plasticizer for the higher unsaturated CTLA if used in connection with a compatible polymer.

All tests performed up to this stage of the investigation were carried out with the aim of narrowing the choices of basic ingredients to be selected for the development of preparations meeting the requirements believed to be essential to accomplish the project objectives. Most of the preliminary tests were carried out on sandy soil, which has been selected for the initial investigation,

because it lacks cohesiveness and, in a loose, dry state, it is susceptible to being disturbed and rutted by traffic.

The experiments carried out in the work described on the following pages of this report were designed to develop preparations meeting the quality requirements stipulated by the U.S. Army Corps of Engineers. Certain test methods have been developed by the Corps at WES for the specific purpose of verifying findings indicating the usefulness of preparations for dust control. The quality requirements and procedures have been described in several documents (13,14,15). Methods 1B, 2B, 3B, and 4, described in Appendix II, have been modeled after the WES testing procedures and are believed to give results which are equivalent to those of the verification tests run at WES on preparations submitted for final evaluation.

The test results reported in Table XI are expressive of the ability of the emulsions to penetrate soils. Samples of the three soil types specified by the Corps of Engineers were used for these tests. Before choosing the particular soil specimens, it was ascertained that the soils closely resembled the soils used at Vicksburg in the verification tests. The soils are defined in Table A-III and Figure A-3. The test procedure is described in Appendix II as Method 5. The principal finding of the test was that the unsaturated and polar solvent, GN-104, aids considerably in penetration into the soil. The data in Tables XI and XII indicate that at least 40 percent of the solvent system should consist of the polar solvent, GN-104, if penetration into clay soil is to be accomplished.

#### Tests Carried Out at WES

In order to establish reference points of performance, seven samples selected from the latest series of tests were shipped to Vicksburg for preliminary evaluation. These samples were selected primarily on the basis of those tests which revealed certain "self-healing" properties of treated soils. The following tabulation identifies the samples.

# Sample Numbers

Table XI	Table XII	WES Designation
262	--	1168
265	--	1172
264	--	1170
268	--	1171
272	--	1169
266	--	1166
--	300	1167

It was suggested that the emulsions should be applied at a rate of 3/8 gallon of concentrate per one square yard of soil surface using the following dilutions:

- (1) Two parts of emulsion to 1 part of water
- (2) One part of emulsion to 1 part of water
- (3) One part of emulsion to 4 parts of water

The recommendation to use different amounts of total fluid to be sprayed onto the soil was to demonstrate the influence of concentration on depth of penetration and amount of coating of the soil particles.

The tests carried out in Vicksburg revealed two major shortcomings of the samples submitted. One was slow penetration particularly into clay, and the other slow drying of the liquid which had not penetrated.

Observations of the performance tests and discussions held in Vicksburg suggested that some sacrifice has to be made in the self-healing properties of treated soils in order to achieve better curing (drying) with clay soils and greater ability to resist the detrimental effect of load in the case of sandy soils.

In consultation with personnel at the WES, it was established that for a product to constitute a better solution of the problem in accord with the requirements stipulated in the directive dated 1 August 1966, Department of the Army, "Approved Qualitative Material Requirement (QMR) For Dust Control Material," it should:

- (1) penetrate all soils likely to be encountered to a depth at least sufficient to anchor the material to the soil.
- (2) form a solidified layer in 4 hours which will resist the impact of rain and wind as determined by WES tests.

- (3) form a water-resistant surface without sealing the surface in a manner as to prevent evaporation of water from below the surface.

It was stated by the project investigators that it would be advantageous if the products would possess some self-healing properties, i.e., be at least easily repaired in place by reworking and, if needed, by hand spray application.

The preparations produced previous to this work were modified to give products which on application to soil, will dry in four hours to provide a surface capable of sustaining limited traffic. The main efforts were directed towards sandy soils which, as demonstrated in the trafficability test in Vicksburg, pose the greatest difficulties. The formulations used were based on the three ingredients chosen as providing the best combination of properties, namely:

- (1) a thermoplastic elastomer which does not require a curing agent or application of heat.
- (2) a coumarone-indene resin which gives stiffness to treated soil at the same time functioning as a plasticizer for the polymer.
- (3) a polar unsaturated resinous oil consisting of a concentrate of nitrogen bases which proved to have good solvency for the polymers tested and to provide good penetration into the soils.

#### Selection of Main Ingredients for Resin System

Having established that a combination of a thermoplastic elastomer, such as Kraton 101 or Kraton 102, a solid resin such as the coumarone-indene resin, Neville R16, and a polar unsaturated resinous oil such as GN-104, constitutes a practical blend of ingredients for soil consolidation, it appeared important to select a suitable solvent not only to facilitate the blending of the three ingredients but also to aid in the penetration and deposition of the blend when applied to soils.

The next step in formulating the final preparation was to establish a practical ratio of polymer:resin:oil. To this end, a series of solutions of the three ingredients in trichlorethylene was prepared and the quality of dry films obtained after evaporation of the solvent was rated visually. The blends reported in Table XIII gave suitable deposits in the form of flexible strong homogeneous matrices. The strength of the deposits decreases from sample 305 to 312,

while ease of handling increases in that order. This is in line with the fact that the molecular weight and viscosity of the products decrease in the order: Kraton 101 > Kraton 102 > Neville R16 > GN-104. The cost of ingredients also decreases for the blends in the order shown, i.e., from blends 305 to 312. Judged on the basis of best all-around properties, blends 305, 307, and 308 appear most desirable; blend 312 appears least desirable because of low strength of the matrix formed.

Preliminary orientation tests employing Methods 1B, 2B, 3B and 4 and observation of surface characteristics of the treated soils suggested that an aromatic hydrocarbon solvent such as xylene and a fire-resistant polar solvent such as trichlorethylene should be employed in addition to the nitrogen bases concentrate GN-104 in order to increase solubility of the polymer and of the resin, and to comply with safety requirements.

In order to test the effect of blend 305 on soils, emulsion 313 was then prepared using, for the sake of expediency, toluene and cyclohexane as diluents. This solvent combination facilitated blending and emulsification but gave an emulsion of low flash point which, although undesirable, was considered unimportant for the purposes of the test. Emulsion 313 (laboratory sample designation II-5-2) was then shipped to Vicksburg for verification of results obtained in our laboratory which indicated that the preparation should meet all WES requirements. Work was continued to establish the best ratio of trichlorethylene to xylene to be used, which solvents were found to be an excellent solvent pair to achieve the desired viscosity, solvency, and fire resistant characteristics. The ratio of xylene to trichlorethylene was found to be important to satisfy the requirement of emulsion stability which is influenced by the specific gravity of the solvent blend.

Utilizing the information developed in the preceding study, emulsion 314 (laboratory sample designation II-8-1) was prepared. Samples 313 and 314 were then subjected to the tests described in Appendix II under Methods 1B, 2B, 3B and 4. Table XIV, giving the composition of the three component emulsions, shows that sample 314 has the additional advantage over 313 in having not only a higher flash point but also a higher content of solids.

Table XV shows the test results which indicate that both emulsions 313 and 314 could be expected to meet the Corps of Engineers' requirements as determined by WES laboratory tests. Emulsion 314 (laboratory designation II-8-1) was then sent to Vicksburg. The tests run at the WES showed that, although neither material passed all the laboratory tests, both the "II-5-2" and "II-8-1" (emulsions 313 and 314) were sufficiently effective to indicate a potential for dust control. Further, of these two systems, emulsion 314 appeared to be more generally suitable than 313 over the range of soil types and soil conditions examined. On this basis, a larger quantity of emulsion 314 was ordered by the WES for further evaluation under random traffic and helicopter downwash tests.

This completes the work on resinous systems under the present contract.

## PART TWO--LATEX SYSTEMS

### Introduction

The latex systems investigated in this part of the project were based on commercially available latices of elastomers. The objective was to explore the possibilities of employing latex systems in applications to soils by spray-on techniques for dust control. PART ONE of this report describes the work dealing with polymers used as reinforcing agents for such unsaturated resinous petroleum fractions as used in the proprietary Product B.

The investigation of latex systems was carried out with the aim of accomplishing two different effects. One was solidification of soils by using the system as a penetrating hinder; the other was the deposition of an elastic film bound to the soil surface. One conceivable use of a suitable latex system as discussed here is combining it with a resinous system as described in PART ONE of this report or a bituminous product as discussed later in PART THREE to achieve a combined effect of both systems, such as a solidified soil layer of some depth covered with a thin elastic membrane-like layer.

### Selection of Base Polymer

The large number of polymer latices available today precludes comprehensive testing of all individual products on the market. Preliminary screening tests were therefore conducted to select types, and then individual latices, for further investigation. The ability of latices to penetrate into soil was used as the first criterion in the selection. Latex samples, representative of types potentially useful for the project, were obtained and tested by Method 5 for penetration into Antioch sand. The latices were used as received, without diluting or compounding, in the first series of tests at an application rate of three pounds per square yard. The test results are recorded in Table XVI.

The first three latices used in the tests reported in Table XVI are acrylic resin latices of the type used in latex-based exterior paints. Resins of this type were

expected to be useful because their films have a combination of desirable properties, particularly high resistance to passage of water and rapid rate of transmission of water vapor. This combination of properties could be expected to yield a surface which is not readily penetrated by water but does allow evaporation of subsurface moisture. Since, of the three acrylic latices tested, two yielded brittle films, only the more flexible Dow Latex 2647 was used for further tests.

The three latices which did not penetrate into the soil in the tests reported in Table XVI were tested further diluted with water to lower solids content (to lower viscosity) and in some cases with the addition of potassium hydroxide as a stabilizer. The improved penetration obtained is shown in Table XVII. After these preliminary tests had established the feasibility of obtaining satisfactory penetration rates with several types of latex, work was directed toward improving the strength and toughness of the films, for instance by means of vulcanization as described later in the discussion of Table XVIII. A qualitative test of the practicability of extending latex with Bitumuls SS-1h, an emulsion of paving asphalt, showed that this appears to be a promising approach for lowering cost without sacrificing desirable properties.

Natural rubber requires vulcanization to obtain optimum physical properties; although vulcanization (curing) is usually done in the dry state (after coagulation and drying of the latex), natural rubber latex can be prevulcanized in the latex state with films cast subsequently having good physical properties. Detailed information on compounding and prevulcanization of latex are not available in the literature. Therefore, in order to follow this route, two latex compounds were developed which were capable of prevulcanization. Optimal conditions for prevulcanization of the compounds were then established. Results of these experiments to develop a satisfactory prevulcanized latex are summarized in Table XVIII.

The table reports the two compound formulations, the conditions of prevulcanization which gave five typical prevulcanized latices, and the properties of dried films cast from these prevulcanized latices. A series of tests was run to determine the optimal conditions for producing the prevulcanized latices reported in Table XVIII. As can be seen from the data presented, samples No. 337, 338 and 339 are superior to samples No. 336 and 342. Control sample No. 340, unvulcanized, serves to show the improvement in properties achieved by prevulcanization. Sample No. 341 shows that the prevulcanized latex is equivalent to normally



vulcanized latex in modulus and elongation; tensile strength is lower but adequate. Since the purpose of these tests was merely to produce a product adequate for testing the feasibility of employing latex systems based on prevulcanized latex, no attempt was made to improve on the formulation and conditions of prevulcanization, although this could certainly be done.

Prevulcanized latex formulation No. 336 and blends of it with other materials, aiding in penetration and/or reinforcing the binders, were tested using Method 5 for penetration into Antioch sand. The results, reported in Table XIX, show that rapid penetration into sandy soil can be achieved by stabilization with potassium hydroxide or by blending with an emulsion of GN-104 which was found to improve penetration of the resinous systems discussed in PART ONE. Due to the plasticizing effect of GN-104, the deposited binder was quite soft and sticky. Changes in the formulations would be required to overcome this shortcoming. It would have been outside the scope of this preliminary study to devote time to this improvement, which is certainly attainable, as is shown by sample No. 345, a blend of acrylic latex with natural rubber latex, which blend is superior to either latex by itself.

The tests reported in Table XX show that no significant penetration into clay soil (Illite) was achieved with the latex formulations used.

#### Wind and Water Erosion Tests

Table XXI shows the results obtained in testing latex formulations on Antioch sand by Methods 1B, 2B, 3B, and 4. As can be seen, all the specimens passed the initial wind test, but only some of the samples passed the water erosion test and the subsequent wind test. Examination of the specimens showed that many formulations had not coagulated at the end of the initial 4 hour period and therefore the binders were readily washed out. Inspection of the retained specimens showed, however, that many of the formulations which failed became quite strongly bound after longer curing periods. In some cases formation of a surface skin delayed drying and coagulation. These shortcomings could be corrected by suitable compounding to achieve more complete penetration and more rapid coagulation. Although, as mentioned above, several of the formulations passed the tests, inspection of the specimens indicated that load-bearing capacity could be expected to be poor after only 4 hours drying but increases substantially as drying

continues to the 16-20 hour test period specified for the last stage of the WES test. Therefore, none of the samples were submitted for testing at WES. Nevertheless, the tests carried out demonstrated the feasibility of producing latex systems for the purposes of the project and are thus not to be considered negative. The results obtained indicate that latex systems offer the possibility to provide, either by themselves if properly compounded, or in blends with other systems, preparations which would accomplish both solidification of soils to some finite depth and formation of a bound surface film. Lack of time did not permit further development work on latex formulations under the present contract.

## PART THREE--BITUMINOUS MATERIALS

### Introduction

According to previous work carried out by the Corps of Engineers at WES on the group of bituminous materials, one proprietary product, identified as Product A, was singled out as having certain desirable properties, if judged relative to conventional cut-back asphalts on the basis of penetration into soils and forming a firm surface in a short period of time. The product was originally designed to serve as a paving material capable of being applied to dirt roads and similar surfaces by spray-on applications. Another proprietary product, identified in the present report as Product C, is marketed for the same purpose. This second product differs from Product A in chemical composition and durability characteristics as determined by procedures described elsewhere (16,17). These procedures have been used extensively to grade asphalts by performance predictable from original chemical composition (17,18,19).

After analyzing Products A and C and reviewing the information available on the two products, a bituminous product was prepared in our laboratory similar to the base bitumen contained in Products A and C to serve as a base product for the present investigation. This base bitumen has been labeled "Asphalt S". The main purpose of producing this base product was to eliminate the possibility of variations in results caused by possible changes in composition of the two proprietary products which might be reformulated by their producers from time to time, as is often the case with new products. Physical and chemical characteristics measured on samples of the two proprietary products are shown in Table XXII together with those for Asphalt S.

In accord with the objective of the project, the work performed on this phase of the investigation was to arrive at an improved bituminous material of the type described in Reference (1) as belonging to Group III. However, it developed in the course of the experimentations that some of the findings reported in PART ONE of this report could be profitably implanted into the phase of the work described in this part of the report as presented below.

### Base Bitumen

As can be seen from the data reported in Table XXII for the recovered asphalts of the two proprietary products, A and C, and for the Asphalt S, the bituminous base material used in this study has been selected primarily to be a durable binder after being once deposited in the soil. The basis for selection has been described in the literature (17,18,19). Briefly described, it has been shown that asphalt performance is governed by chemical composition if determined in terms of groups of components of decreasing chemical reactivity and that the parameter  $(N + A_1)/(P + A_2)$ , representing the ratio of highly reactive to less reactive components, correlates with durability. It is, of course, realized that for the purposes of the present project, durability is of minor importance and that high durability might actually be undesirable. In either case, the fact presented regarding interdependence of composition of base asphalt and durability of the binder is valuable information in that it offers the possibility of producing at will a highly durable binder or one of limited durability, as may be required for military purposes. It makes it possible, for instance, to employ a surfacing material of specified short life expectancy for use in advanced and temporary theaters of operation where permanent installations might be undesirable for tactical reasons, and, on the other hand, highly durable paving materials in areas where permanent improvements are desirable. The other properties of the preparation, such as penetration into surfaces, inflammability, and viscosity, can be controlled by the type and amount of solvent used. The base asphalt of the present investigation was designed to have a composition parameter,  $(N + A_2)/(P + A_2)$ , of 0.8 to 1.2, assuring good durability in asphalts of a consistency of less than 100 penetration. Higher penetration grade asphalts can tolerate higher values and still give good durability.

### Penetration of Bituminous Systems Into Soils

Penetration of bituminous materials into soils depends primarily on soil porosity, viscosity of the bituminous material, and conditions of surface activity of both the soil and the bituminous preparation. Resistance to penetration increases as grain size of soil decreases, with fine-grained clays offering the greatest resistance to penetration. Resistance to penetration also increases with increasing moisture content of soils, primarily because as the interstices between grains are filled with water, the channels for penetration are closed to the binder. This

holds particularly true for hydrophilic soils to be treated with systems based on hydrocarbon solvents which cannot displace the water strongly held by capillary forces and by surface adsorption. In spite of this obvious phenomenon, it is almost a general engineering practice to spray water on dusty soils to reduce surface tension. Correct practice to combat surface dust is not to wet the soil to be treated with water but with a hydrophobic fluid such as a hydrocarbon solvent containing a cationic surfactant. In the case of the bituminous system with which this phase of the investigation deals, the best material for combating surface dust is a kerosene solution of the preparation itself. In tests carried out with Product C, which has a solids content of approximately 64 percent, previous to this investigation, it has been established that pretreatment of soils with the diluted product of only 20 percent concentration constitutes the best method of conditioning the soil for the follow-up treatment.

In order to verify the statement that maximal effectiveness is achieved by using a 20 percent solution for pretreatment, the test described in Appendix II as Method 6 was used. Briefly stated, the test consisted of molding briquets shaped to have a depression on the top, to serve as a receptacle for the fluid to be tested, pouring the test fluid into this depression, and noting time, depth and nature of penetration. The test results obtained with briquets made from silty sand are presented in Table XXIII and Figures 1 through 5. Figures 6 through 11 are photographs of the test specimens. Figure 6 shows the control, Figures 7 and 8 the reduction of penetration caused by pretreatment with water, Figures 9 through 11 show that dilution to 20 percent solids provides the best material for pretreatment.

In cutting the briquets distinct shades were observed in the treated soil, giving the appearance of different layers. The first "layer", deepest in color, represents the depth of penetration of the preparation applied in the second treatment; the bottom of the second layer, the depth of penetration of the pretreatment; while the third layer shows the depth of solvent percolation caused by displacement by subsequent treatment of the solvent contained in the diluted preparation used in the pretreatment. When using water for pretreatment, the pores are blocked and no penetration is obtained. These phenomena are clearly discernible with the naked eye. The data presented in Table XXIII and Figures 3 through 5 show that best results are obtained by pretreatment with 0.5 gallons per square yard of a 20 percent solution followed by 1 to 1.5 gallons per square yard treatment with the concentrate.

The above reported results were obtained using silty sand as the test soil. When using Pittsburg clay and Illite, penetration into the specimens was negligible. It was concluded from these results that bituminous products of the type represented by Product A and Product C are, if properly applied, useful in treating dirt roads and other relatively porous, coarse-grained structures if they do not contain high amounts of clay. Field trips made to inspect areas where the two products were applied commercially confirmed this conclusion.

Tests carried out subsequent to those described above were, in view of the observations reported, aimed at improving the penetration characteristics of Asphalt S solutions. The first step was to determine whether or not the polar resinous product, GN-104, used successfully for improving penetration of resinous systems, as described in PART ONE of this report, could be employed for the same purpose in a solvent system as used with the bituminous material.

Table XXIV, reporting the results of these tests, shows that GN-104 aids penetration of bituminous solution systems into soils in a manner similar to that found with resinous systems formulated as emulsions.

In order to check further on the effect of polar solvents on penetration into soils, a low boiling distillate from product GN-104 was tested as a stepwise replacement for the regular kerosene type solvent. The results are reported in Table XXV. These tests were carried out using Antioch sand and Pittsburg clay. No significant penetration could be obtained into specimens produced from Illite.

In accord with the observations reported earlier that pretreatment of hydrophilic soils with a hydrophobic solvent should aid in penetration, Illite was pretreated with kerosene and low boiling nitrogen bases distillate and then tested as to receptiveness to treatment with a bituminous material. The results are shown in Table XXVI.

Having established that a polar solvent is desirable in this type system and taking into account the need for a nonflammable solvent system, trichlorethylene was used instead of the low boiling fraction of nitrogen bases in the following tests, which were primarily designed to test the influence of the consistency (hardness) of the bituminous base material on drying characteristics and appearance of treated soils. The formulations tested are shown in Table XXVII. The solutions were applied to Antioch sand

at a rate of 0.33 gallons per square yard. Visual examination of the treated specimens showed that the effectiveness of the solution increased as the hardness of the asphalt increased, and the content of GN-104 was decreased. Sample No. 403 produced treated soils of the best appearance judged on the basis of penetration rate, depth of penetration, and firmness of the treated soil.

The observations discussed above led to the conclusion that bituminous preparations useful for the purposes defined should be based on a low penetration grade asphalt (10-30 pen), dissolved in a solvent consisting chiefly of trichlorethylene, a minimum amount of xylene and a small amount of a cationic surfactant. Of various blends produced, the one designated as formula II-11-1 was found to have the desirable high solids content and sufficiently low viscosity for ease of application. A solution prepared according to this formula applied to Antioch sand at the rate of 1 gallon per square yard penetrated into the soil specimen within 30 minutes to a depth of 0.4 inch. The soil surface was dry and tack-free within 1 hour. These results compared favorably with those obtained with Product A which took 2 hours to penetrate and gave a surface which was quite tacky after 4 hours. A sample of preparation II-11-1 was sent to Vicksburg for testing. The product did not pass the sequence of tests set up at WES. The reason for failure with sandy soils was probably that the amount of this material to be applied should be at least 1 gallon per square yard rather than the specified 3/8 gallon which gives insufficient depth of penetration. The difficulty with clays and silts was primarily slow curing.

In order to test the feasibility of increasing the amount of fluid applied to increase depth of penetration without resorting to the use of a higher amount of the bituminous binder, the solution II-11-1 was emulsified using a cationic emulsification system as used with the resinous systems. Composition of formulas II-11-1 and II-11-2 are shown in Table XXVIII.

The emulsion labeled formula II-11-2 was then tested by Methods 1B, 2B, 3B and 4. The results are shown in Table XXIX.

A sample of the product, II-11-2, sent to Vicksburg for testing did not pass the sequence of tests specified. It is believed that both formulas II-11-1 and II-11-2 should be applied at higher rates than 3/8 gallon per square yard to be effective, and that scarifying of soils containing high amounts of clay or silt would be required. Both

products hold promise as paving materials, as represented by Products A and C, but have probably only limited utility if compared with resin systems for the control of dust. Product II-11-2 can also be used in blends with resinous systems as described in PART ONE of this report. It is expected to be quite useful as an extender for such resinous systems and also as an extender for latex systems as described in PART TWO of this report. Time limitation did not permit a thorough investigation of these possibilities but preliminary qualitative tests indicate the potential usefulness of bituminous products as blending materials for the other two systems, the resinous system and the latex system.



## PART FOUR--RESULTS AND RECOMMENDATIONS

### Introduction

The work performed in this investigation comprised three different approaches to the problem of selecting effective dust control agents for use in theaters of operations. Details of the reasoning underlying the work program and of the experimentations are presented in the preceding three parts of this report in accord with the three areas explored.

### Resinous Systems

The main result of the efforts expended in the area of resinous systems, described in PART ONE of this report, was the development of a formula for an all-purpose preparation which is believed to be considerably superior to previously available products. This preparation, identified in the report as "Emulsion No. 314" and "Sample No. II-8-1", can be easily manufactured in large volume at relatively low cost for immediate use. Present cost is \$2.50 per gallon of concentrate. Usually diluted to four times its volume and applied at a rate of 0.75 to 1.5 gallon per square yard, the cost of treating material is approximately \$0.47 to \$0.94 per square yard. Large-scale production and certain changes in formulation are apt to lower the price to \$1.00 per gallon of concentrate or less, reducing the cost per one square yard of treated area to approximately \$0.19 to \$0.38.

Ease of manufacture, availability of raw material, and cost were some of the prime considerations in designing this product. In line with these objectives and for the sake of expediency, i.e., to assure the shortest lapse of time between developing the product and manufacturing it, a pilot plant for manufacture of trial quantities (capacity 100 gallons per day) has been designed and set up in this laboratory. One potential manufacturer was kept informed of the work so that commercial production could be promptly initiated. At the time of the writing of this report, two drums of the product have been produced, one in this laboratory and one by a prospective manufacturer. The latter drum has been shipped to Vicksburg for testing. Since the equipment is simple and a company with experience in manufacturing this type of

product has expressed interest in producing it, it can be assumed that requests for the product will be filled promptly.

In addition to relative ease of manufacture, emulsion 314 has great versatility in that it can be used for all methods of erosion control, defined as the short-range objective in the original program. The versatility of emulsion 314 is given by its ability to bind all types of soils, to be applied diluted with water from the highest to the lowest concentrations and at all rates likely to be specified for spray-on applications. The rate of application governs the depth of penetration into the soils and thus the depth to which the soil is bound; the amount of dilution governs the thickness of the coating of the cementing agent on each soil particle and thus the degree of cementing. This offers the possibility to use dosages of the dust alleviator in a manner adequate to the needs of the terrain and contemplated use.

The work performed on resinous systems yielded, in addition to the formula now available for immediate use in the present emergency a great deal of information regarding the effects of all types of polymers and all types of petroleum resins. Further exploration of the compatible combinations developed could provide additional formulations for resinous systems, which might be more effective, lower in cost, or possibly both. The concept of composite emulsions constitutes another very intriguing approach to the problem of soil treatment giving the possibility of combining in emulsion form otherwise incompatible ingredients to interact in the soil after deposition therein. Although this avenue has not been explored in the present investigation to the stage of being reduced to practice, it unquestionably offers a new method of attack worthy of exploration.

#### Latex Systems

The work presented in PART TWO of this report did not lead to the recommendation of an immediately usable product. However, it was established that latex systems can be developed for soil stabilization purposes and particularly for protection against wind and water erosion. The tendency of the latex systems investigated to form surface membranes which can be peeled off offers the interesting possibility of using these systems as coatings on stock-pile material or other products for temporary protection from erosion in addition to the applications investigated in this project. In cases where ability to penetrate soils to any appreciable depth is desired, this can be accomplished, as has been shown in the investigation, by several measures,

one of which might be the combination of a latex system with a suitable resinous system.

#### Bituminous Materials

The investigation carried out on bituminous materials presented in PART THREE of this report led to the conclusion that bituminous solvent systems are not effective dust palliatives when compared with resinous systems, but should rather be considered paving materials. If applied as such, they are highly useful with coarse-grained soils. Their main value is for constructing temporary roads or treating dirt roads designed for moderate traffic. The formulation developed in the present investigation for this type paving material is far superior to current commercially available products in many respects. The product has better durability, great ability to penetrate surfaces and is nonflammable.

The effective ingredients of the preparation can be compounded as spray-on solution or emulsion, whichever is desired. The emulsion has the advantage that it can be applied in a variety of rates and concentrations similar to the resinous emulsion product and can be used in mixtures with the resinous emulsion. In such mixtures, the bituminous emulsion serves as a low-cost extender in the case where dust control is the most important consideration; and where road surfacing is the main consideration, the resinous emulsion serves as a reinforcing agent imparting toughness and flexibility to the bituminous preparation.

The cost of the bituminous solution is estimated at approximately \$0.50 per gallon, and of the bituminous emulsion at approximately \$1.75 per gallon in pilot plant quantities. Cost would be substantially lower in commercial production, making the product competitive with currently used bituminous materials.

It has also been demonstrated that a two-step application is preferable to a one-step application. Since the first step of the application suggested (0.5 gallon per square yard of the product diluted to 20 percent solids) constitutes a pretreatment usually carried out by applying water, the two steps do not constitute a disadvantage compared with present practice.

#### General Recommendations

The results obtained in the present investigation yielded useful results of immediate applicability in the present emergency. The experiments conducted provided also

a great deal of information of potential utility for long-range objectives of soil treatment at military installations. Further work appears advisable to perfect the products developed and to establish best methods of application.

For the latter purposes the interdependency of dilutions, amounts applied and mode of application and effects attainable should be established.

Field trials should be conducted to explore utility of the products on permanent military installations as well as on installations in advanced theaters of operations.

The additional laboratory studies suggested and field trials should also serve the purpose of collecting data and experience to be used in the preparation of an instruction manual for engineers designing installations and supervising their construction. For instance, nomographs could be developed correlating amounts applied with effects attainable.

Field trials in various locations are also apt to assist in improving the products by revealing requirements of application, actual effectiveness and logistics, usually not established by laboratory tests.

## REFERENCES

1. Kozan, G. R. and R. A. Pimental, Guide Manual for Selection and Use of Dust Palliatives and Soil Waterproofers in the Theater of Operations, Miscellaneous Paper No. 4-756, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, November 1965.
2. Decell, J. L., Dust Alleviators. Report I. Resin- and Latex-Base Concrete Curing Compounds, Miscellaneous Paper No. 4-819, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, June 1966.
3. Rostler, Fritz S., Dust-Laying Emulsions, U.S. Patent No. 2,646,361, July 21, 1953.
4. Rostler, F. S. and B. A. Vallergera, A Manual on Control of Dust and Wind Erosion, Golden Bear Oil Co., Bakersfield, California, 1960.
5. Rostler, F. S. and W. M. Kunkel, Jr., "Soil Stabilization," Ind. Eng. Chem. 56, 27, Apr. 1964.
6. U.S. Army Engineer District CE, Report on Wind Erosion Control for G/M Training Facility 75-1, Vandenberg Air Force Base, Lompoc, California, Los Angeles, September 1960.
7. Peters, John and Joe Sciandrone, "Stabilization of Sand Dunes at Vandenberg Air Force Base," J. Soil Mechanics and Foundations Div., Proc. A.S.C.E. 90, No. SM4, 97, July 1964.
8. Chepil, W. S., N. P. Woodruff, F. H. Siddoway and D. V. Armbrust, Mulches for Wind and Water Erosion Control, U.S. Dept. Agriculture ARS41-84, July 1963.
9. Chepil, W. S., N. P. Woodruff, F. H. Siddoway, D. W. Fryrear and D. V. Armbrust, "Vegetative and Nonvegetative Materials to Control Wind and Water Erosion," Soil Sci. Soc. Am. Proc. 27, No. 1, 86, Jan.-Feb. 1963.
10. Chepil, W. S., Observations on Some Soil Stabilization Work in California, report to U.S. Navy, Washington, D. C., June, 1960, unpublished (for copy see Appendix III).
11. Chepil, W. S., Soil Conditions That Influence Wind Erosion, Technical Bulletin No. 1185, U.S. Dept.

Agriculture, Agricultural Research Service, in cooperation with Kansas Agricultural Experiment Station, Washington, D. C., June, 1958.

12. White, R. M., "Evaluation of a Small Laboratory Wind Machine," unpublished (for copy see Appendix III).
13. U.S. Army Engineer Waterways Experiment Station, CE, Laboratory Procedure and Tests for Screening of Proposed Dust Control Materials, Memorandum WESSS3, Vicksburg, Mississippi, 17 March 1966.
14. U.S. Army Engineer Waterways Experiment Station, Dust Palliatives, Test Equipment Air Nozzle and Stand, drawing MS-329-1, Vicksburg, Mississippi, 1966, unpublished.
15. U.S. Army Engineer Waterways Experiment Station, CE, Traffic Test of Dust-Control Materials, Memorandum WESSS3, Vicksburg, Mississippi, 21 April 1966, revised 27 April 1966.
16. Rostler, F. S. and R. M. White, "Influence of Chemical Composition of Asphalts on Performance. Particularly Durability," Symposium on Road and Paving Materials--1959, ASTM Special Technical Publication 277, pp. 64-88, 1960.
17. Rostler, Fritz S. and Richard M. White, "Composition and Changes in Composition of Highway Asphalts, 85-100 Penetration Grade," Proc. Assoc. Asphalt Paving Technologists 31, 35-79, Discussion 79-89, January, 1962.
18. Rostler, Fritz S., "Prediction of Performance Based on Asphalt Composition Using Precipitation Methods," Proc. Highway Conference on Research and Development of Quality Control and Acceptance Specifications Using Advanced Technology, Vol. 2, pp. 93-158, U.S. Dept. Commerce, Bur. Public Roads, Off. Research and Development, Washington, D. C., April 1965.
19. Halstead, Woodrow J., Fritz S. Rostler and Richard M. White, "Properties of Highway Asphalts--Part III. Influence of Chemical Composition," Public Roads, 34, 17, June 1966.

TABLE 1. VISCOSITIES OF BASE RESIN THICKENED BY 3 WT. % POLYMER

Sample No.	Polymer		Method of Incorporation	Viscosities, cP			
	Designation	Type		Without Additional Heating		After Additional Heating 2 hr/250°C	
				77°F	210°F	77°F	210°F
1	None: Control (Califlux GP)		--	9,580	20.1	no change	
2	None: Control (Califlux 550)		--	1,288,500	108.8	no change	
3	Natural rubber	NR	latex	60,450	634.8	17,020	39.7
4	Pliolite 1502	SBR 51 ML4*	latex	29,800	101.7	22,130	48.3
5	Pliolite 5352	SBR 100 ML4**	latex	50,500	163.4	30,360	64.4
6	Pliolite 491	Carboxylated SBR	latex	-----	-----	not soluble	
7	Pliopave L-165-K	SBR	latex	68,500	277.5	31,800	69.8
8	Goodyear X335	SBR (low MW)	liquid rubber	9,850	25.6	--	--
9	Pliovic 300	PVC	latex	-----	-----	not soluble	
10	Foral 85	Ester resin	dry	14,080	22.8	--	--
11	Thermoplastic 125	Thermoplastic SBR block copolymer	dry	20,790	55.4	--	--
12	Kraton 101	Thermoplastic SBR block copolymer	dry	33,380	96.7	--	--
13	Vistanex LM-MH	Poly(isobutylene) (low MW)	dry	19,220	43.7	--	--
14	Vistanex MML-100	Poly(isobutylene) (high MW)	dry	122,300	871.6	128,200	776.3

\* Medium molecular weight

\*\* High molecular weight

TABLE II. VISCOSITIES OF BASE RESIN-WHITE OIL BLENDS CONTAINING 1.5 WT.% POLYMER

Sample No.	Polymer		Method of Incorporation	Viscosities, cP			
	Designation	Type		Without Additional Heating		After Additional Heating 2 hr/250°C	
				77°F	210°F	77°F	210°F
15	None: Control (Califlux GP) diluted 1:1 with Sample 17		--	446	11.2	no change	
16	None: Control (Califlux 550) diluted 1:1 with Sample 17		--	1,310	18.7	no change	
17	None: White oil		--	135	--	no change	
18	Natural rubber	NR	latex	1,520	75.3	619	15.5
19	Pliolite 1502	SBR 51 ML-4	latex	778	25.2	651	16.1
20	Pliolite 5352	SBR 100 ML-4	latex	1,003	25.2	774	18.4
21	Pliopave L-165-K	SBR	latex	1,074	36.1	758	19.1
22	Goodyear X335	SBR (low MW)	liquid rubber	485	12.7	--	--
23	Foral 85	Ester resin	dry	491	11.8	--	--
24	Thermolastic 125	Thermoplastic SBR block copolymer	dry	1,252	17.4	--	--
25	Kraton 101	Thermoplastic SBR block copolymer	dry	17,420	23.2	--	--
26	Vistanex LM-MH	Poly(isobutylene)	dry	674	16.6	--	--
27	Vistanex MML-100	Poly(isobutylene)	dry	2,188	91.2	2,199	84.6



TABLE III. EROSION RESISTANCE OF SANDY SOIL TREATED WITH 3 LB/YD<sup>2</sup> OF NONIONIC-ANIONIC EMULSIONS  
OF POLYMER SOLUTIONS (METHODS 1A, 2A, 3A)

Sample No.	Polymer	Solvent	Wt. % Polymer		Wind Resistance Method 2A*, mph	Water Resistance Method 3A*, % Remaining		
			Solution	Emulsion**		10'	20'	60'
28	None: Control (Product B)		0.0	0.0	120-160	75	70	10
29	None	Califlux GP	0.0	0.0	100-140	80	60	30
30	Natural rubber	Califlux GP	3	1.8	90-110	75	40	--
31	Natural rubber (heated 2 hr/250°C)	Califlux GP	3	1.8	110-160+	10	0(15')	--
32	Pliopave L-165-K	Califlux GP	3	1.8	80-100	80	50	--
33	Vistanex L-100	Califlux GP	3	1.8	110	40	15	--
34	Pliolite 5352	Califlux GP	3	1.8	90	75	40	--
35	Pliolite 5352 (heated 2 hr/250°C)	Califlux GP	3	1.8	120-160+	40	10	--
36	IR 700	Califlux GP	3	1.8	100	75	20	--
37	Goodyear X335	Califlux GP	3	1.8	100-130	40	10	--
38	Kraton 101	Califlux GP	3	1.8	70-100	50	--	--
39	Kraton 101	1:1 Califlux GP: white oil	1.5	0.9	120-150	0	--	--
40	Kraton 101	Califlux GP	1.5	0.9	120-150	75	--	--

\* See Appendix

\*\* Containing 60% of solution, 40% water + emulsifier

TABLE IV. COMPARISON OF ANIONIC AND CATIONIC EMULSIFICATION SYSTEMS--  
EFFECT ON SOIL (METHODS 1A, 2A, 3A)

Sample No.	Composition of Oil Phase			Emulsification System*,	Wind Resistance Method 2A**, mph	Water Resistance Method 3A**, % Remaining		
	Solvent	Polymer				10'	20'	60'
		Designation	Wt. %					
29	Califlux GP	none	0.0	A+N	100-140	80	60	30
157	Califlux GP	none	0.0	C	140-160	90	80	70
156	Product B (Coherex)	none	0.0	N	120-160	75	70	10
33	Califlux GP	Vistanex L-100	3	A	110	40	15	--
178	Califlux GP	Vistanex L-100	3	C	90-110	75	60	50
39	1:1 Califlux GP:white oil	Kraton 101	1.5	A	120-150	0	--	--
190	1:1 Califlux GP:white oil	Kraton 101	1.5	C	130-145	0	--	--
38	Califlux GP	Kraton 101	3	A+N	70-100	50	--	--
187	Califlux GP	Kraton 101	3	C	90-120	80	60	--

\* A = anionic, C = cationic, N = nonionic

\*\* See Appendix

TABLE V. OIL PHASE OF CATIONIC EMULSIONS

Sample No.	Polymer			Solvent
	Designation	Type	g	
41	none	--	0	Califlux GP
42	none	--	0	Philrich 5
43	none	--	0	Califlux 550
44	none	--	0	SR stock
45	none	--	0	White oil
46	none	--	0	CTLA
47	none	--	0	RP220
48	none	--	0	GN-104
49	Vistanex I-100	Poly(isobutylene) MW 90,000	3	Califlux GP
50	Vistanex L-100	Poly(isobutylene) MW 90,000	6	Califlux GP
51	Natural rubber	NR (from latex)	3	Califlux GP
52	S-1502	SBR	3	Califlux GP
53	Thermolastic 125	SBR Thermoplastic block copolymer	3	Califlux GP
54	Kraton 101	SBR Thermoplastic block copolymer	10	Califlux GP
55	Foral 85	Ester resin	3	Califlux GP
56	Parlon	Chlorinated natural rubber	3	Califlux GP
57	Dow PS-2	Poly(styrene) MW 20,000	10	Califlux GP
58	Dow PS-2	Poly(styrene) MW 20,000	30	Califlux GP
59	Dow PS-3	Poly(styrene) MW 30,000	20	Califlux GP
60	Kraton 101	SBR Thermoplastic block copolymer	6	GN-104
61	Chemigum N-615	NBR (from latex)	3	GN-104
62	Chemigum N-615	NBR (from latex)	12	GN-104
63	Hycar 1441	NBR (high nitrile)	1	GN-104
64	Hycar 1441	NBR (high nitrile)	2	GN-104
65	Hycar 1441	NBR (high nitrile)	5	GN-104
66	Hycar 1441	NBR (high nitrile)	6	GN-104
67	Hycar 1441	NBR (high nitrile)	10	GN-104
68	Hycar 1441	NBR (high nitrile)	12	GN-104
69	Hycar 1441	NBR (high nitrile)	15	GN-104
70	Hycar 1442	NBR (medium nitrile)	15	GN-104
71	Natural rubber	NR (RSS No. 1)	6	CTLA
72	Natural rubber	NR (RSS No. 1)	3	CTLA
73	S-1502	SBR	12	CTLA
74	Kraton 101	SBR Thermoplastic block copolymer	6	60/40 Califlux GP/GN 104
75	S-1502	SBR	3	50/50 Califlux GP/GN 104
76	S-1502	SBR	3	50/50 CTLA/GN-104

TABLE VI. BLENDS OF POLYMER SOLUTIONS (Page 1 of 3)

Polymer Solution	Sample No.	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
10% Kraton 101 in GP		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
12% Chemigum N615 in GN-104		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
10% Kraton 101 in GP		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
3% Chemigum N615 in GN-104		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
3% Vistanex L-100 in GP		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
3% NR in GP		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
3% Parlon in GP		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
3% Fural 85 in GP		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
3% S-1502 in GP		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
3% Vistanex LF in GP		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
3% Pilotite 5352 in GP		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
3% X335 in GP		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Consistency Rating*		HG	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
		SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
		V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C

\*Rating

Amount of Gel

HG - high

MG - medium

LG - low

NG - none

Appearance of Gel

SS - strong string

Sh - short string

Viscosity

V - fluid as base resin

V - higher viscosity than base resin

Compatibility

C - compatible

2P - phase separation

TABLE VI. continued (Page 2 of 3)

[illegible]

* Rating:	Amount of G-1
1	100
2	100
3	100
4	100
5	100
6	100
7	100
8	100
9	100
10	100
11	100
12	100
13	100
14	100
15	100
16	100
17	100
18	100
19	100
20	100
21	100
22	100
23	100
24	100
25	100
26	100
27	100
28	100
29	100
30	100
31	100
32	100
33	100
34	100
35	100
36	100
37	100
38	100
39	100
40	100
41	100
42	100
43	100
44	100
45	100
46	100
47	100
48	100
49	100
50	100
51	100
52	100
53	100
54	100
55	100
56	100
57	100
58	100
59	100
60	100
61	100
62	100
63	100
64	100
65	100
66	100
67	100
68	100
69	100
70	100
71	100
72	100
73	100
74	100
75	100
76	100
77	100
78	100
79	100
80	100
81	100
82	100
83	100
84	100
85	100
86	100
87	100
88	100
89	100
90	100
91	100
92	100
93	100
94	100
95	100
96	100
97	100
98	100
99	100
100	100

**High**

MG medium

100

111

2007

## Viscosity

F. fluid as base resin

$\nu$  : higher viscosity than base resin

### Compatibility

C = compatible

2p : phase separation

100

TABLE VI. continued (Page 2 of 3)

Polymer Solution	Sample No.		134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155
	Polymer Solution																							
10% Kraton 101 in GP					33	33	33	33	33	33								33						
12% Chemigum NG15 in GN-104										33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
3% Kraton 101 in GP											33													
3% Chemigum NG15 in GN-104			33	33													33	33	33	33	33	33	33	33
3% Vistanex I-100 in GP					33							33					33				33			
3% NR in GP						33											33							
3% S-1502 in GP							33								33							33		
3% Vistanex 1R in GP			33													33								33
3% Pliolite 5352 in GP			33	33																				
Callifix GP			33	33																				
SR Stock					33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Consistency Rating*			NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
			--	--	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	--	--	--	--	--	--	--	--
			F	F	V	V	V	V	V	F	Sh	Sh	Sh	Sh	Sh	F	F	F	F	F	F	F	F	F
			C	C	C	C	C	C	C	C	2P	2P	2P	2P	2P	C	C	2P	C	2P	C	2P	2P	C
*Rating	Amount of Gel	Amount of Gel			Appearance of Gel				Viscosity														Compatibility	
	HC - high	MC - medium			SS - strong string				F - fluid as base resin														C - compatible	
	LG - low	NG - none			Sh - short string				V - higher viscosity than base resin														2P - phase separation	

TABLE VII. FROSTION RESISTANCE OF SANDY SOIL TREATED WITH CATIONIC EMULSIONS (Methods 1A, 2A, 3A)

Sample No.	Composition of Emulsion				Emulsification System**	Dilution	Wind Resistance Method 2A***, mph	Water Resistance Method 3A***, % Remaining		
	Solvent	Designation	Polymer					10'	20'	60'
			% in Solution	% in Emulsion						
156	Product B-Control				N	1:4	120-160	75	70	10
157	Califlux GP	0	6	0	C	1:4	140-160	90	80	79
158	Philrich S	6	0	0	C	1:4	120-140	80	75	60
159	SR Stock	0	0	0	C	1:4	80-120	75	60	50
160	GN-104	0	0	0	C	1:5	110-150	95	90	90
161	CTLA	0	0	0	C	1:5	50-140 (no cohesion)	0(3')	brittle	
162	Califlux GP	Kraton 101	10	6	C	1:4	140-160+	90	80	60
163	GN-104	Chemigum N-615*	3	1.8	C	1:4	140-160+	90	80	--
164	N-104	Chemigum N-615*	18	12.6	C	1:5	100-120	90	90	90
165	GN-104	Chemigum N-615*	16.5	11.5	C	1:5	100-130	90	90	90
166	GN-104	Chemigum N-615*	12	8.4	C	1:5	80-130	90	90	80
167	GN-104	Chemigum N-615*	3	2.1	C	1:5	90-100	80	80	70
168	GN-104	Hycar 1441	1	0.6	C	1:5	110-130	80	75	66
169	GN-104	Hycar 1441	2	1.2	C	1:5	90-130	90	90	75
170	GN-104	Hycar 1441	5	3	C	1:5	90-130	95	90	80
171	GN-104	Hycar 1441	10	6	C	1:5	40-60*	101*	51*	0†
172	GN-104	Hycar 1441	12	8.4	C	1:5	90-130	90	90	90
173	GN-104	Hycar 1441	15	11.5	C	1:5	100-140	80	80	80
174	GN-104	Hycar 1441	15	9	C	1:5	40-80†	21†	10†	0†
175	GN-104	Hycar 1442	12	6.4	C	1:5	80-110	90	90	80
176	Califlux GP	S-1502	3	1.8	C	1:4	90	80	50	50
177	Califlux GP	Vistanex I-100	3	1.8	C	1:4	100	90	80	80
178	Califlux GP	Thermastatic 125	3	1.8	C	1:4	90-110	75	60	50
179	Califlux GP	Foral 85	3	1.8	C	1:4	110-130	75	60	50
180	Califlux GP	Dow PS-2	10	7	C	1:5	100-150	90	90	90
181	Califlux GP	Dow PS-3	20	14	C	1:5	70-110	60	50	40

\* Incorporated as latex

\*\* N = nonionic, C = cationic

\*\*\* See Appendix

† Required heating 29 hr at 150-170°C to attain complete solution

(†) Faulty specimens. Poor wind and water erosion resistance due to prolonged drying (60 hr) at 125°F and poor coating because of coarseness of emulsion.

TABLE VIII. EROSION RESISTANCE OF SAND SOIL TREATED WITH BLENDS OF EMULSION (Methods 1A, 2A, 3A) (Page 1 of 3)

Sample No.	Samples Blended	Solvent	Composition of Blends			Emulsification Systems	Dilution	Wind Resistance Method 2A***, mph	Water Resistance Method 3A***, % Remaining 10', 20', 60'
			Investigation	Nonionic	Cationic				
182	182 + 186	Califlux GP GN-104	0	0	0	C	1:5	90-130	75 70 60
183	183 + 187	Califlux GP CTA	0	0	0	C	1:5	120-160	90 90 80
184	182 + 187	Califlux GP White oil	Kraton 101	5	3	C	1:4	70-110	20 5 0
185	182 + 187	Califlux GP White oil	Kraton 101	5	5	C+N	1:4	100-150	10 0 --
186	182 + 187	Califlux GP White oil	Kraton 101	3	1.3	C+N	1:4	110-130	0 -- --
187	182 + 186	Califlux GP	Kraton 101	3	1.3	C+N	1:4	90-120	80 60 --
188	182 + 186	Califlux GP White oil	Kraton 101	5	3	C+N	1:4	90-110	90 75 --
189	182 + 186	Califlux GP White oil	Kraton 101	1.5	0.9	C+N	1:4	100-150	50 0 --
190	182 + 186	Califlux GP White oil	Kraton 101	1.5	0.9	C+N	1:4	130-145	0(7') -- --
191	182 + 186	80 Califlux GP 20 White oil	Kraton 101	1.5	0.9	C+N	1:4	120-150	60 25 --
192	182 + 186	Califlux GP White oil	Kraton 101	8	4.8	C+N	1:4	60-100	50 30 --
193	182 + 186	Califlux GP White oil	Kraton 101	1.5	1.0	C	1:4	100-140	10 5 0
194	182 + 182	Phirich 5 Califlux GP	Kraton 101	5	3	C	1:6	130-140	95 95 80
195	182 + 182	SR Stock Califlux GP	Kraton 101	5	3	C	1:4	110-130	95 90 80
196	182 + 186	Califlux GP	Kraton 101	5	3	C	1:4	50-90	50 40 10
197	182 + 186	Califlux GP GN-104	Chemikur N-615	6	3.6	C	1:6	155-160 no loss	70 60 50
198	182 + 186	Phirich 5 GN-104	Chemikur N-615	6	3.6	C	1:4	90-110	60 50 30
199	182 + 186	Califlux GP GN-104	Chemikur N-615	6	4.2	C	1:5	110-140	95 90 80
200	182 + 184	Califlux GP GN-104	Chemikur N-615	9	6.3	C	1:5	130-150	90 90 80

\* Cationic white oil emulsion, 50% solids  
 \*\* Nonionic, C = cationic  
 \*\*\* See Appendix



TABLE VIII. continued (page 2 of 3)

Sample No.	Sample Blending	N Level	Composition of Blends		Emulsification System*	Dilution	Wind Resistance Method 2A**, mph	Water Resistance Method 3A**, % Remaining 10', 20', 60'
			Designation	Portion in Solution				
201	157 + 162	Califlux GP GN-104	Chemikum N-615	1.5	1.0	1:5	140-160	90 80 80
202	159 + 166	SR Stock GN-104	Chemikum N-615	6	3.6	1:4	130-160+	80 75 75
203	159 + 166	SR Stock GN-104	Chemikum N-615	6	3.6	1:7	150-160+	-- -- --
204	157 + 163	Califlux GP GN-104	Chemikum N-615	1.5	0.9	1:4	90-140	90 90 70
205	156 + Califlux 550	GN-104	Chemikum N-615	6	3.6	1:4	70-120	60 50 20
206	156 + White oil (N)	GN-104	Chemikum N-615	1.5	0.9	1:4	110-140	0(3+) -- --
207	157 + 166	Califlux GP GN-104	Chemikum N-615	6	3.6	1:4	100-120	70 60 20
208	159 + 166	SR Stock GN-104	Chemikum N-615	6	3.6	1:5	160 no loss	70 60 50
209	159 + 166	SR Stock GN-104	Chemikum N-615	6	3.6	1:4	120-140	50 25 20
210	159 + 166	SR Stock GN-104	Chemikum N-615	6	3.6	1:4	100-120	50 40 <10
211	159 + 163	SR Stock GN-104	Chemikum N-615	1.5	0.9	1:4	130-160+	80 80 40
212	160 + 166	GN-104	Chemikum N-615	6	3.6	1:5	100-140	90 90 75
213	157 + 173	Califlux GP GN-104	Hycar 1441	7.5	5.2	1:5	110-150	90 80 70
214	157 + 172	Califlux GP GN-104	Hycar 1441	6	4.2	1:5	90-140	90 90 80
215	157 + 170	Califlux GP GN-104	Hycar 1441	2.5	1.5	1:5	100-120	80 70 50
216	157 + 169	Califlux GP GN-104	Hycar 1441	1	0.6	1:5	80-140	90 90 90
217	159 + 170	SR Stock GN-104	Hycar 1441	2.5	1.5	1:5	100-150	70 60 50
218	159 + 169	SR Stock GN-104	Hycar 1441	1	0.6	1:5	90-150	60 50 40
219	159 + 168	SR Stock GN-104	Hycar 1441	0.5	0.3	1:5	110	70 60 50
220	157 + 172	Califlux GP GN-104	Hycar 1441	7.5	5.2	1:5	100-150	90 80 80

\* N = nonionic, A = anionic, C = cationic

\*\* See Appendix

TABLE VIII. continued (Page 3 of 3)

Sample No.	Samples Blended	Solvent	Composition of Blends			Emulsification System*	Dilution	Wind Resistance Method 2A**, mph	Water Resistance Method 3A**, % Remaining 10', 20', 50'
			Designation	Polymer in Solution	% in Emission				
221	136 + 177	SR Stock Califlux GP	Vistanex L-100	1.5	0.9	C	1:4	80-110	95 90 80
222	162 + 166	Califlux GP GN-104	Kraton 101 Chemigum N-615	(5) 11 (6)	(3) 6.6 (3.6)	C	1:4	110-160	-- --
223	162 + 166	Califlux GP GN-104	Kraton 101 Chemigum N-615	(5) 11 (6)	(3) 6.6 (3.6)	C + 0.5 N	1:4	110-140	-- --
224	166 + 177	GN-104 Califlux GP	Chemigum N-615 Vistanex L-100	(6) 7.5 (1.5)	(3.6) 4.5 (0.9)	C	1:6	130-160+ slight loss	90 80 75
225	161 + 177	GN-104 Califlux GP	Chemigum N-615 Vistanex L-100	(6) 9 (3)	(3.6) 5.4 (1.8)	C	1:5	110-150	90 90 90
226	162 + 180	GN-104 Califlux GP	Chemigum N-615 Dow PS-3	(6) 16 (10)	(3.6) 10.6 (7)	C	1:5	100-150	90 90 80
227	172 + 186	GN-104 Califlux GP	Hycar 1441 Dow PS-3	(3.2) 13.2 (10)	(2.2) 9.2 (7)	C	1:5	100-150	90 90 70
228	173 + 177	GN-104 Califlux GP	Hycar 1441 Vistanex L-100	(6) 9 (3)	(4) 6.5 (2.5)	C	1:5	90-160	90 90 90
229	172 + 177	GN-104 Califlux GP	Hycar 1441 Vistanex L-100	(1.5) 4.5 (3)	(0.9) 2.7 (1.8)	C	1:5	90-120	90 70 60
230	170 + 177	GN-104 Califlux GP	Hycar 1441 Vistanex L-100	(2.5) 4.0 (1.5)	(1.5) 2.4 (0.9)	C	1:5	110-150	70 50 40
231	172 + 181	GN-104 Califlux GP	Hycar 1441 Dow PS-3	(6) 16 (10)	(3.6) 10.6 (7)	C	1:5	150-160	90 90 80
232	177 + 181	Califlux GP	Vistanex L-100 Dow PS-3	(3) 9.7 (6.7)	(1.8) 7.1 (5.3)	C	1:5	110-130	90 80 80
233	161 + 177	CTLA Califlux GP	Vistanex L-100	1.5	0.9	C	1:5	90-110	90 80 80
234	161 + 181	CTLA Califlux GP	Dow PS-3	10	7	C	1:5	110-140	80 60 40
235	137 + 187 S-1502 in CTLA	CTLA Califlux GP	S-1502	6	3.6	C	1:5	100-120	95 95 95

\* C = Califlux; N = neolonic

\*\* See Appendix

TABLE IX. EROSION RESISTANCE OF SANDY SOIL SPECIMENS, SURFACE TREATED WITH EMULSIONS AND EMULSION BLENDS (Methods 1B, 2B, 3B)

Sample No.	Samples Blended	Solvent	Composition of Blends				Emulsification System†	Wind Resistance Method 2B*, mph	Water Resistance Method 3B*, % Remaining 10', 20', 60'
			Designation	Polymer		% in Emulsion			
				Solution	% in				
236	Product B-Control		0	0	0	N	160 no loss	-- 90	
237	157	Califlux GP	0	0	0	C	150 trace 160 no loss	-- 100	
238	158	Philrich 5	0	0	0	C	110-150 trace 160 no loss	-- 100	
239	159	SR Stock	0	0	0	C	120-160 slight loss	-- 100	
240	157 + 162	Califlux GP	Kraton 101	5	3	C	160 trace	-- 100	
241	159 + 166	SR Stock GN-104	Chemigum N-615	6	3.6	C	160 no loss	-- 100	
242	162 - 166	Califlux GP GN-104	Kraton 101 Chemigum N-615	(5) (6)	(3) (3.6)	C	120 trace 160 no loss	-- 100	
243	166 + Califlux 550 (C)**	GN-104 Califlux 550	Chemigum N-615	6	3.6	C	160 no loss	-- 100	
14	162 + 166	Califlux GP GN-104	Kraton 101 Chemigum N-615	(5) (6)	(3) (3.6)	C + 0.5 N	140 trace 160 no loss	-- 100	
245	159 + 162 + 166	Califlux GP(25) SR Stock(25) GN-104(50)	Kraton 101 Chemigum N-615	(2.5) (2.6)	5.1 3.1 (1.5) (1.6)	C	160 no loss	-- 100	

\* C cationic, N = nonionic

† See Appendix

\*\* Cationic emulsion of Califlux 550, 60% solids

TABLE X. EROSION RESISTANCE OF SANDY SOILS TREATED WITH COMPOUNDED EMULSIONS (Methods 1A, 2A, 3A)

Sample No.	Samples Blended	Solvent	Composition of Emulsion			Emulsification System*	Wind Resistance Method 2A**, mph 20" Nozzle Angle	Water Resistance Method 3A**, % Remaining 10' 20' 60'		
			Designation	Polymer	% in Solution	% in Emulsion				
246	160	GN-104†	0		0	0	120-160+	70	60	50
247	--	GN-104 AG††	0		0	0	120-160+	50	40	30
248	157 + 161	Califlux GP CTLA	0		0	0	70-90	90	90	80
249	159 + 162	Philrich f Califlux GP	Kraton 101		5	3.3	130-150+	95	95	95
250	157 + 163	Califlux GP GN-104	Chemigum N-61S		1.5	1.05	80-120	90	80	70
251	157 + 172	Califlux GP GN-104	Hycar 1441		6	4.2	80-140	90	90	80
252	157 + 172	Califlux GP GN-104	Hycar 1441		3	2	130-160+	80	80	70
253	157 + 172	Califlux GP GN-104	Hycar 1441		1.5	1	130-150+	90	90	90
254	172 + 169	GN-104 Califlux GP	Hycar 1441 Dov PR-3		13.2	9.2	60-90	90	90	70
255	--	CTLA	S-1502‡		12	8.4	too brittle to test			
256	157 + 255	Califlux GP CTLA	S-1502		6	4.2	130-140+	95	95	90
257	--	CTLA (75) Califlux GP (25)	NR		3	2	80-110	70	60	50

\* C = cationic, N = nonionic

\*\* See Appendix

† Specified boiling range

‡ Containing low boiling fraction

TABLE XI. PENETRATION RATE INTO TEST SOILS OF COMPOUNDED CATIONIC EMULSIONS DILUTED TO 30% SOLIDS (Method 5)\* (Page 3 of 2)

Sample No.	Composition of Emulsions				Penetration Rate**			Appearance of Treated Soils After 24 hr		
	Solvent	Designation	Polymer g/g in Solution	% in Emulsion	Antioch Sand	Pittsburg Clay	Illite	Antioch Sand	Pittsburg Clay	Illite
259	Product B-Control	0	0	0	2	2	4	dry, soft	dry, soft	dry, soft
260	Semi-Pave-Control	0	0	0	3	3	5	dry, firm	dry, firm	tacky skin
261	UCAR-130-Control	0	0	0	2	2	5	dry, hard	dry, hard	hard skin
262	Califlux GP	0	0	0	2	2	4	dry, soft	dry, soft	dry, soft
263	Philrich 5	0	0	0	2	2	4	dry, soft	dry, soft	dry, soft
264	GN-104	0	0	0	1	1	2	dry, soft	dry, soft	dry, firm
265	C*LA	0	0	0	2	2	5	dry, hard	dry, hard	tacky skin
266	Califlux GP	Kraton 101	10	3	3	4	5	dry, firm	dry, soft	sticky
267	C*LA	NR	6	1.8	2	2	5	dry, hard	dry, hard	firm, slightly tacky
268	C*LA	NR	3	0.9	2	2	5	dry, hard	dry, hard	tacky skin
269	75 C*LA 25 Califlux GP	NR	0.75	0.22	2	2	5	dry, hard	dry, hard	soft skin
270	C*LA	S-1502	12	3.6	2	2	5	dry, hard	dry, hard	tacky skin
271	GN-104	Hycar 1441	12	3.6	--	--	--	--	--	--
272	GN-104	Hycar 1441	6	1.8	1	1	2	dry, soft	dry, firm	dry, firm
273, Blend of 262-271	50 Califlux 3P 50 GN-104	Hycar 1441	6	1.8	1	1	4	dry, firm	dry, firm	tacky
274, Blend of 266-272	50 Califlux GP 50 GN-104	Kraton 101 Hycar 1441	6 3	(1.5)2.4 (0.9)3.4	1	3	4	dry, firm	dry, firm	dry, firm

\* See Appendix

\*\* 1 - 1 minute or less; 2 - 1-5 minutes; 3 - 5-30 minutes; 4 - more than 30 minutes; 5 - no penetration

TABLE XI. continued (Page 2 of 2)

Composition of Emulsions			Penetration Rate*			Appearance of Treated Soils After 24 hr				
Sample No.	Solvent	Polymer Designation	% in Solution	% in Emulsion	Anticoh Sand	Pittsburg Clay	Illite	Anticoh Sand	Pittsburg Clay	Illite
273 Blend of 263-265 50 Calflux GP of 263-265 50 GN-104		Hycar 1441	3	0.9	1	1	2	dry, soft	dry, firm	dry, solid
275 Blend of 263-265 50 Polirich 5 of 263-265 50 Calflux GP		Kraton 101	6	1.5	3	3	5	dry, soft	dry, soft	tacky skin
277 Blend of 265-267 CTIA		NR	3	0.9	2	2	5	dry, hard	dry, hard	hard skin
278 Blend of 263-265 50 Calflux GP of 263-265 50 CTIA		NR	3	0.9	2	2	5	dry, hard	dry, hard	hard skin
279 Blend of 265-270 CTIA		S-1502	6	1.4	2	2	5	dry, hard	dry, hard	hard skin
280 Blend of 261-268 Calflux GP of 261-268		UCAR-150	60	30	2	2	5	dry, hard	dry, hard	hard skin
281 Blend of 262-265 75 Calflux GP of 262-265 25 CTIA		0	0	0	2	2	5	dry, hard	dry, hard	hard skin
282 Blend of 264-268 50 GN-104 of 264-268 50 Calflux GP		Kraton 101	6	1.5	2	2	4	dry, soft	dry, soft	dry, soft
283 Blend of 261-267 50 GN-104 of 261-267 50 CTIA		NR	6	1.5	1	1	2	dry, soft	dry, soft	dry, soft
284 Blend of 264-268 50 GN-104 of 264-268 50 CTIA		NR	7	0.9	1	1	2	dry, soft	dry, soft	dry, soft
285 Blend of 263-265 50 GN-104 of 263-265 50 CTIA		0	0	0	1	1	3	dry, soft	dry, soft	dry, soft
286 Blend of 263-265 50 Calflux GP of 263-265 50 CTIA		0	0	0	3	3	5	dry, firm	dry, firm	tacky skin
287 R9220		0	0	0	1	1	3	dry, firm	dry, firm	oily skin solid
288 CN-104		Kraton 101	6	1.6	1	1	1	dry, firm	dry, firm	dry, firm
289 50 Calflux GP of 50 GN-104		Kraton 101	6	1.8	1	1	2	dry, firm	dry, firm	dry, firm
290 50 Calflux GP of 50 GN-104		S-1502	7	0.9	1	1	3	dry, firm	dry, firm	dry, firm
291 50 CFL of 50 GN-104		S-1502	3	0.9	1	1	3	dry, firm	dry, firm	dry, firm

\* 1 = 1 minute or less; 2 = 1-5 minutes; 3 = 5-30 minutes; 4 = more than 30 minutes; 5 = no penetration

TABLE XII. PENETRATION RATE INTO TEST SOILS OF COMPOUNDED CATIONIC EMULSIONS DILUTED TO 40% SOLIDS (Method G)\*

Sample No.	Composition of Emulsions			Penetration Rate**		Appearance of Treated Soil After 24 hr
	Solvent	Designation	% in Solution	% in Emulsion	Pittsburg Clay	Illite
292	Califlux GP	0	0	0	3	--
293	CTLA	0	0	0	3	--
294	75 CTLA 25 GN-104	0	0	0	--	5
295	50 GN-104 50 UCAR-130	PVAc	30	12	--	5
296	50 GN-104 50 RP-220	0	0	0	--	2
297	CTLA	NR	3	1.2	3	--
298	GN-104	Hycar 1441	6	2.4	2	--
299	50 Philrich 5 50 Califlux GP	Kraton 101	10	4	4	--
300	50 Califlux GP 50 GN-104	Kraton 101 Hycar 1441	(5) 8 (3)	(2) 32 (1.2)	2	--
301	90 Califlux GP 10 GN-104	0	0	0	4	5
302	45 Califlux GP 45 Philrich 5 10 GN-104	Kraton 101	4.5	1.8	4	5
303	75 Califlux GP 25 GN-104	0	0	0	3	4
304	37.5 Califlux GP 37.5 Philrich 5 25 GN-104	Kraton 101	3.75	1.5	3	4

\* See Appendix

\*\* 1 = 1 minute or less; 2 = 1-5 minutes; 3 = 5-30 minutes; 4 = more than 30 minutes; 5 = no penetration

TABLE XIII. RATIOS OF POLYMER: RESIN: OIL

Sample No.	Kraton 101	Kraton 102	Neville R-16	GN-104
305	1	-	1	1
306	-	1	1	1
307	1	-	1.5	1.5
308	-	1	1.5	1.5
309	1	-	2	1.5
310	-	1	2	1.5
311	1	-	2	2
312	-	1	2	2



TABLE XIV. THREE COMPONENT EMULSIONS

Sample No.	313	314
Lab. Designation	II-5-2	II-8-1
Composition	Weight %	Weight %
Kraton 101	13.0	--
Kraton 102	--	12.2
Neville R-16	13.0	18.3
GN-104	13.0	18.3
Cyclohexane	19.5	--
Toluene	6.5	--
Trichlorethylene	--	18.3
Xylene	--	6.1
Redicote E-1	2.0	1.9
Acetic acid (glacial)	1.0	1.0
Water	32.0	23.9
Total solids	42.0	51.7
Specific gravity	0.946	1.068

TABLE XV. EROSION TESTS OF TEST SOILS TREATED WITH THREE COMPONENT EMULSIONS (Methods 1B, 2B, 3B, 4)\*

Sample No.	Dr. lot ion ratio	Dr. lot ion applied, rat. vol.	Test Soil	penetration Time, minutes	Drying Time, hours	Initial Wind Erosion--50, 100, 150 over 250 mph	Water Erosion After 1 hour	Wind Erosion After water Test--50, 100, 150, over 250 mph	Wind Erosion After Drying 16-20 hr & 1 hr @ 125 F--50, 100, 150, over 250 mph
313	1:1	0.85	Antioch sand	1.5	4	no loss	no loss	no loss	no loss
	1:2	0.85	Antioch sand	2.0	4	no loss	no loss	no loss	no loss
	1:4	2.0	Antioch sand	2.0	4	no loss	no loss	no loss	no loss
	1:3	0.85	Antioch sand	2.0	1	no loss	no loss	no loss	no loss
	1:1	0.85	Antioch sand	2.0	1	no loss	no loss	no loss	no loss
	1:2	0.85	Antioch sand	16	2	no loss	no loss	no loss	no loss
313	1:1	0.85	Antioch sand	3	2	no loss	no loss	no loss	no loss
	1:2	0.85	Pittsburg clay	3	4	no loss	no loss	no loss	no loss
	1:4	1.25	Pittsburg clay	3	4	no loss	no loss	no loss	no loss
	1:4	2.0	Pittsburg clay	20	4	no loss	no loss	no loss	no loss
	1:4	0.85	Pittsburg clay	1	2.5	no loss	no loss	no loss	no loss
	1:1	0.85	Antioch sand	10	4	no loss	no loss	no loss	no loss
314	1:1	0.85	Antioch sand	1.5	4	no loss	no loss	no loss	no loss
	1:2	0.85	Antioch sand	1.1	4	no loss	no loss	no loss	no loss
	1:3	0.85	Antioch sand	1.1	4	no loss	no loss	no loss	no loss
	1:1	0.85	Antioch sand	1.1	4	no loss	no loss	no loss	no loss
	1:4	0.85	Antioch sand	1.1	4	no loss	no loss	no loss	no loss
	1:2	0.85	Antioch sand	1.1	4	no loss	no loss	no loss	no loss

\*See Appendix

TABLE XVI. TESTING OF POLYMER LATICES (Method 5)\*

Sample No.	Latex			Penetration Into Antioch Sand		Appearance of Treated Soil After 24 hr Drying
	Designation	Type	% Solids	Rate†	Depth, inch	
317	Dow 2647	Acrylic	47	2	1/4	firm, slightly flexible
318	Rhoplex AC33	Acrylic	46	2	1/4	firm, brittle
319	Acrylene 45	Acrylic	55	4	1/8	firm, brittle
320	Neoprene 571	CR	50	5	none	soft, flexible skin
321	Natural rubber	NR	62	5	none	soft, flexible skin
322	Pliolite 491	Carboxylated SBR	57	2	1/4	firm, slightly flexible
323	Pliolite 610	Carboxylated SBR	50	5	none	firm, flexible skin
324	Pliolite 491 (cationic)	Carboxylated SBR	50	4	1/4	firm, slightly flexible

\* See Appendix

† 1 = 1 minute or less; 2 = 1-5 minutes; 3 = 5-30 minutes; 4 = more than 30 minutes; 5 = no penetration

TABLE XVII. TESTING OF DILUTED LATICES (Method 5)\*

Sample No.	Latex		Stabilizer (KOH) Added, phr**	Penetration Into Antioch Sand		Appearance of Treated Soil After 24 hr Drying
	Designation	Type		Rate†	Depth, inch	
325	Neoprene 571	CR	---	5	none	soft, flexible skin
326	Natural rubber	NR	---	5	none	soft, flexible skin
327	Natural rubber	NR	---	4	3/32	soft, flexible
328	Natural rubber	NR	1	4	3/16	soft, flexible
329	Natural rubber	NR	1	2	3/16	soft, flexible
330	Pliolite 610	Carboxylated SBR	---	4	3/32	firm, flexible
331	Pliolite 610	Carboxylated SBR	---	4	1/8	firm, flexible
332	Pliolite 610	Carboxylated SBR	---	4	3/16	firm, flexible
333	Pliolite 610	Carboxylated SBR	---	4	3/16	firm, flexible
334	Pliolite 610	Carboxylated SBR	1	1	1/8	firm, flexible
335	Pliolite 610	Carboxylated SBR	0.4	4	3/32	firm, flexible

\* See Appendix

\*\* Parts on one hundred parts of rubber

† 1 = 1 minute or less; 2 = 1-5 minutes; 3 = 5-30 minutes; 4 = more than 30 minutes; 5 = no penetration

TABLE XVIII. COMPOSITION AND PROPERTIES OF PREVULCANIZED NATURAL RUBBER LATEX FILMS

Ingredients	Parts (dry basis)						
	336	337	338	339	340	341	342
Natural rubber				100			100
Potassium hydroxide				0.50			0.50
Triton X-200				0.50			0.50
Zinc diethyldithiocarbamate				1.00			1.00
Sulfur				0.75			2.10
Zinc oxide				1.00			1.00
AgeRite Spar				1.50			1.50
Zinc mercaptobenzothiazole				--			1.00
Sample No.	336	337	338	339	340	341	342
Prevulcanization temperature, °C	65	70	75	80	*	**	55
Optimum prevulcanization time, minutes	55	60	35	30	*	**	60
Physical Properties of Dried Films							
Modulus at 500% elongation, psi	195	190	175	220	95	200	225
Tensile strength at break, psi	2015	2780	2970	2685	1430	4840	2130
Elongation at break, percent	1125	935	990	895	1105	970	875

\* Unvulcanized

\*\* Not prevulcanized, but vulcanized 90 minutes at 80°C in conventional manner after casting

TABLE XIX. PENETRATION TESTS OF PREVULCANIZED LATEX INTO ANTIOCH SAND (Method 5)\*

Sample No.	Formulation	Wt. % Solids	Stabilizer (KOH) Added phr**	Penetration Rate† Depth, inch	Appearance of Surface After 24-hr Drying
343	Prevulcanized NR No. 336	45	-	5	soft, flexible skin
344	Prevulcanized NR No. 336	45	1	1	soft, flexible skin
345	50% Prevulcanized NR No. 336 50% Dow 2647	46	-	1	firm, flexible skin
346	50% Prevulcanized NR No. 336 50% GN-104	50	-	4	weak, tacky
347	50% Prevulcanized NR No. 336 50% GN-104	40	-	1	weak, tacky

\* See Appendix

\*\* Parts on one hundred parts of rubber

† 1 = 1 minute or less; 2 = 1-5 minutes; 3 = 5-30 minutes; 4 = more than 30 minutes;

5 = no penetration

TABLE XX. PENETRATION TESTS OF LATEX FORMULATIONS INTO ILLITE (Method 5)\*

Sample No.	Formulation	Wt. % Solids	Penetration Rate† inch	Appearance of Treated Soil After 24-hr Drying
348	Pliolite 491	57	5	firm, flexible skin
349	Pliolite 491	35	5	firm, flexible skin
350	50% Prevalcanized NR No. 336 50% Dow 2647	40	5	firm, flexible skin
351	50% Prevalcanized NR No. 336 50% GN-104	40	5	soft, tacky skin
352	50% Prevalcanized NR No. 336 50% GN-104	30	5	soft, tacky skin
353	50% Prevalcanized NR No. 336 50% GN-104	20	5	soft, tacky skin
354	50% Dow 2647 50% GN-104	40	5	flexible skin
355	50% Pliolite 491 (cationic) 50% GN-104	40	5	flexible skin

\* See Appendix

† 1 = 1 minute or less; 2 = 1-5 minutes; 3 = 5-30 minutes; 4 = more than 30 minutes;

5 = no penetration

TABLE XXI. EROSION TESTS OF ANTIOCH SAND TREATED WITH LATEX FORMULATIONS (Methods 19, 2B, 3B, 4)\*

Sample No.	Formulation	% Solids	Initial Erosion 100, 150, 230 mph	Water Erosion After 1 Hour	Wind Erosion After Water Test--50, 100, 150, over 230 mph	Wind Erosion After Drying 16-20 hr & 1 hr @ 125 F-50, 100, 150, over 230 mph
356	50% Prevulcanized NR No. 338 50% Dow 2647	50	no loss	failed < 1 min. (latex washed out)	--	--
357	75% Prevulcanized NR No. 338 25% Dow 2647	32	no loss	failed < 1 min. (latex washed out)	--	--
358	75% Prevulcanized NR No. 338 25% Pliolite 480	34	no loss	failed < 1 min. (latex washed out)	--	--
359	50% Prevulcanized NR No. 338 50% Pliolite 610	31	no loss	failed < 1 min. (latex washed out)	--	--
360	67% Prevulcanized NR No. 338 33% Asphalt	30	no loss	no loss, skin loose	failed 15 sec @ 150	--
361	50% Prevulcanized NR No. 338 50% Asphalt	20	no loss	intact but some latex washed out	failed 2 sec @ 100	--
362	33% Prevulcanized NR No. 338 33% Pliolite 460 33% Asphalt	29	no loss	failed < 1 min. (latex washed out)	--	--
363	33% Prevulcanized NR No. 338 33% Pliolite 480 33% Asphalt	29	no loss	failed < 1 min. (latex washed out)	--	--
364	33% Prevulcanized NR No. 338 33% Pliolite 610 33% Asphalt	27	no loss	no loss	no loss	no loss
365	67% Pliolite 610 33% Asphalt	27	no loss	no loss	failed 15 sec @ 230	--
366	50% Pliolite 610 50% Asphalt	28	no loss	no loss	no loss	no loss
367	33% Pliolite 610 67% Asphalt	28	no loss	no loss, skin loose	failed 7 sec @ 230	--
368	33% Pliolite 610 67% Asphalt	19	no loss	no loss	no loss	no loss
369	25% Pliolite 610 75% Asphalt	29	no loss	no loss	failed 10 sec @ 230	--
370	25% Pliolite 610 72% Asphalt	75	no loss	no loss, skin loose	no loss	no loss
371	25% Pliolite 610 75% Asphalt	21	no loss	no loss, skin loose	failed 4 sec @ 150	--
372	25% Pliolite 610 75% Asphalt	19	no loss	no loss, skin loose	failed 15 sec @ 150	--
373	100% Asphalt	30	no loss	failed < 1 min.	--	--

\* See Appendix



TABLE XXII. TYPICAL CHARACTERISTICS OF BITUMINOUS PRODUCTS  
FOR SPRAY-ON TREATMENT OF ROADS

	Product A		Product C		Asphalt S
	374	375	376	377	
Sample No.					378
Recovered Asphalt*, Wt. %	56	68	67	66	--
Solvent, Wt. %	44	32	33	34	--
Properties of Base Asphalts					95
Penetration**	47	21	249	212	
Chemical Analysis***, %					
A (Asphaltenes)	32.8	23.7	19.0	22.1	
N (Nitrogen bases)	37.9	27.0	31.1	29.5	
A <sub>1</sub> (First acidaffins)	17.6	25.1	12.9	11.5	
A <sub>2</sub> (Second acidaffins)	7.6	17.0	17.0	16.9	
P (Paraffins)	4.1	7.2	20.0	20.0	
Composition Parameter, $\frac{N + A_1}{P + A_2}$	4.74	2.15	1.19	1.11	
Durability Group†	V	V	II	II	
Average abrasion, % loss†	100	100	--	0.25	0.25
Properties of Solvents					--
Sp. Gr.	0.83	0.81	0.84	0.85	

\* ASTM Method D402

\*\* ASTM Method D5

\*\*\* Method in Reference (17)

† Method in Reference (18); I = superior, II = good, III = satisfactory, IV = fair,

V = inferior

TABLE XXIII. PENETRATION OF PRODUCT C INTO SILTY SAND BRIQUETS

Sample No.	Pretreatment with Asphalt Solution of 20% Solids	Time and Depth of Penetration	Treatment with Product C, 64% Solids			
			0	0.5	1.0	1.5
	Gallons per square yard					
379	0.0	Time	--	245 sec	539 sec	1008 sec
		Depth layer 1	--	0.18 in.	0.29 in.	0.36 in.
		Depth layer 2	--	--	--	--
		Depth layer 3	--	--	--	--
380	0.5	Time	--	215 sec	572 sec	985 sec
		Depth layer 1	0.45 in.	0.34 in.	0.49 in.	0.55 in.
		Depth layer 2	--	0.69 in.	0.77 in.	0.74 in.
		Depth layer 3	--	--	--	--
381	1.0	Time	--	213 sec	541 sec	1039 sec
		Depth layer 1	0.64 in.	0.41 in.	0.50 in.	0.58 in.
		Depth layer 2	0.80 in.	0.83 in.	0.87 in.	0.91 in.
		Depth layer 3	--	1.02 in.	1.06 in.	1.12 in.
382	1.5	Time	--	282 sec	540 sec	990 sec
		Depth layer 1	0.77 in.	0.45 in.	0.55 in.	0.63 in.
		Depth layer 2	0.95 in.	0.91 in.	1.01 in.	1.02 in.
		Depth layer 3	--	1.18 in.	1.10 in.	1.10 in.

TABLE XXIV. INFLUENCE OF GN-104 ON PENETRATION RATE  
OF BITUMINOUS BINDER

Sample No.	54% Asphalt S Solution, %	GN-104, %	Penetration Time Into Antioch Sand, seconds
383	100	0	668
384	90	10	452
385	75	25	354
386	0	100	395

TABLE XXV. COMPARISON OF EFFECTS OF DIFFERENT DILUENTS  
ON PENETRATION RATE INTO SOIL

Sample No.	Ingredients, %*			Penetration Time, sec	
	Asphalt S	Kerosene	Nitrogen Bases Distillate	Antioch Sand	Pittsburg Clay
387	65	34.5	0	690	612
388	65	25.5	9	764	--
389	65	22.5	12	494	529
390	65	17.25	17.25	240	157
391	65	0	34.5	491	456

\* All formulations contain 0.5% surfactant

TABLE XXVI. PENETRATION RATE INTO PRETREATED ILLITE

Sample No.	Ingredients, %*		Amount & Time of Penetration for 0.17 gsy	
	Asphalt	S Kerosene	Nitrogen Bases Distillate	Pretreated with 0.08 gsy Kerosene
392	65	34.5	0.0	95% in 8 hr
393	65	25.5	9.0	95% in 8 hr
394	65	22.5	12.0	98% in 8 hr
395	65	17.25	17.25	Complete in 1.5 hr
396	65	0.0	34.5	Complete in 4.5 hr
				Pretreated with 0.08 gsy 50/50 kerosene/nitrogen bases distillate
				80% in 5 hr
				98% in 5 hr
				90% in 5 hr
				Complete in 2.0 hr
				Complete in 2.75 hr

\*All formulations contain 0.5% surfactant

TABLE XXVII. RAPID-DRYING FIRE-RESISTANT LIQUID ASPHALT FORMULATIONS

Ingredients, %	Sample No.									
	397	398	399	400	401	402	403			
Asphalt, 85-100 pen (Asphalt S)	65	65	--	--	--	--	--			
Asphalt, 40-50 pen	--	--	--	65	--	--	--			
Asphalt, 10-20 pen	--	--	65	--	65	65	70			
Xylene	6.5	6.5	6.5	6.5	20	5	4.5			
Trichlorethylene	28	18	18	18	--	14.5	25			
GN-104	--	10	10	10	15	15	--			
Surfactant	0.5	0.5	0.5	0.5	0.5	0.5	0.5			

TABLE XXVIII. COMPOSITION OF BITUMINOUS SOLUTION  
AND BITUMINOUS EMULSION SUBMITTED TO WES

Sample No. Designation	404 II-11-1	405 II-11-2
Ingredients, %		
Asphalt, 25 pen	70.0	52.50
Xylene	7.0	5.25
Trichlorethylene	22.5	16.875
Redicote 2323	0.5	0.375
Redicote E-1	--	2.0
Acetic Acid (glacial)	--	1.0
Water	--	22.0

TABLE XXIX. EROSION TESTS (Methods 1B, 2B, 3B, 4)\*  
OF ANTIOCH SAND TREATED WITH PREPARATION II-11-2,  
SAMPLE NO. 405

Dilution with Water	2:1	1:1	1:2
Dilution Applied, gal/yd <sup>2</sup>	1.0	1.0	1.0
Penetration Time, minutes	1.25	<1	<1
Initial Wind Erosion up to +230 mph	no loss	no loss	no loss
Water Erosion after 1 hr	no loss	no loss	no loss
Wind Erosion, up to + 230 mph, after Water Test	no loss	no loss	no loss
Wind Erosion, up to +230 mph, after drying 16-20 hr @ R.T. and 1 hr @ 125°F	no loss	no loss	no loss

\* See Appendix



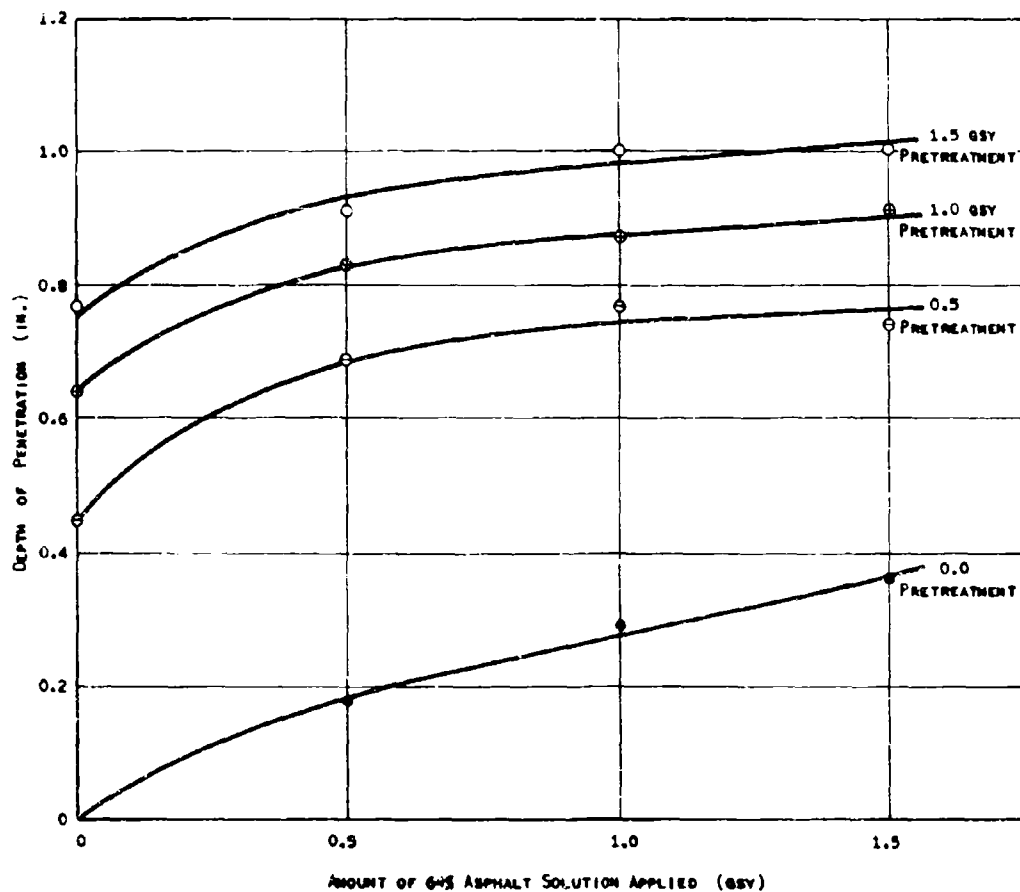


FIG. 1 - EFFECT OF APPLICATION RATES OF PRETREATMENT (20% ASPHALT) AND OF POSTTREATMENT (64% ASPHALT) ON PENETRATION INTO SILTY SAND BRIQUETTES

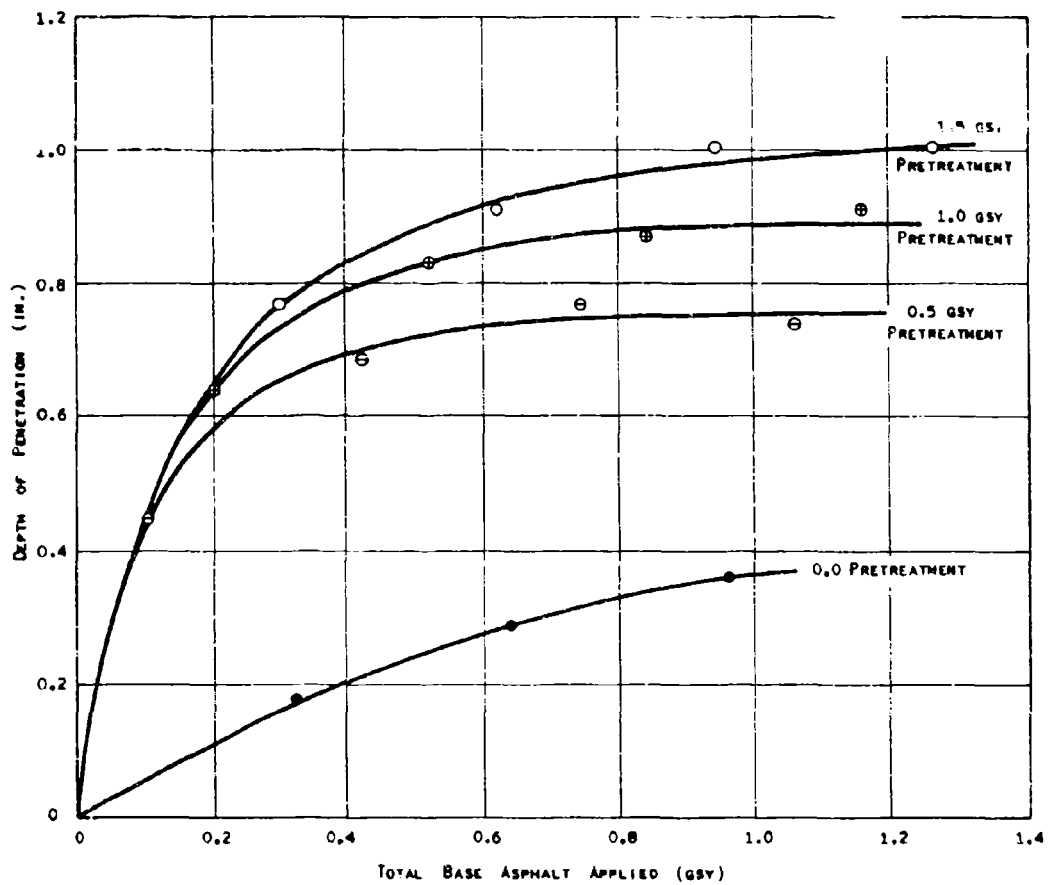


FIG. 2 - EFFECT OF TOTAL AMOUNT OF BASE ASPHALT APPLIED ON DEPTH OF PENETRATION

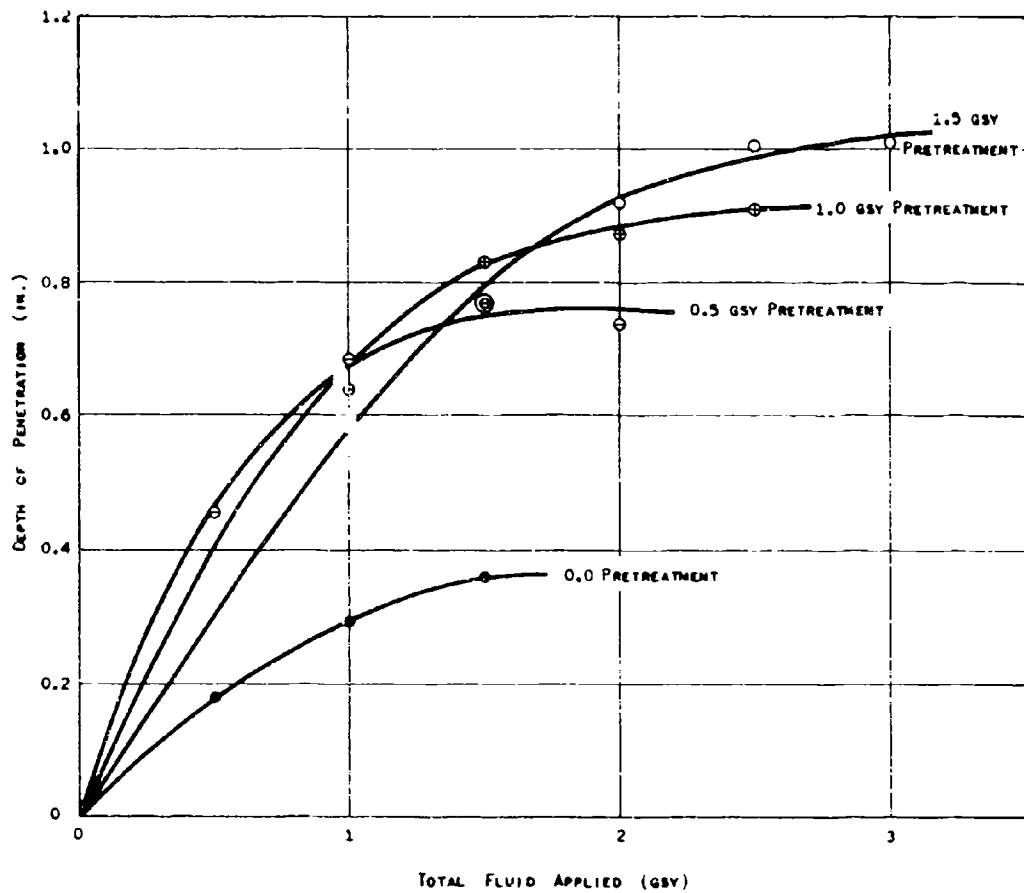


FIG. 3 - EFFECT OF TOTAL QUANTITY OF FLUID APPLIED ON DEPTH OF PENETRATION

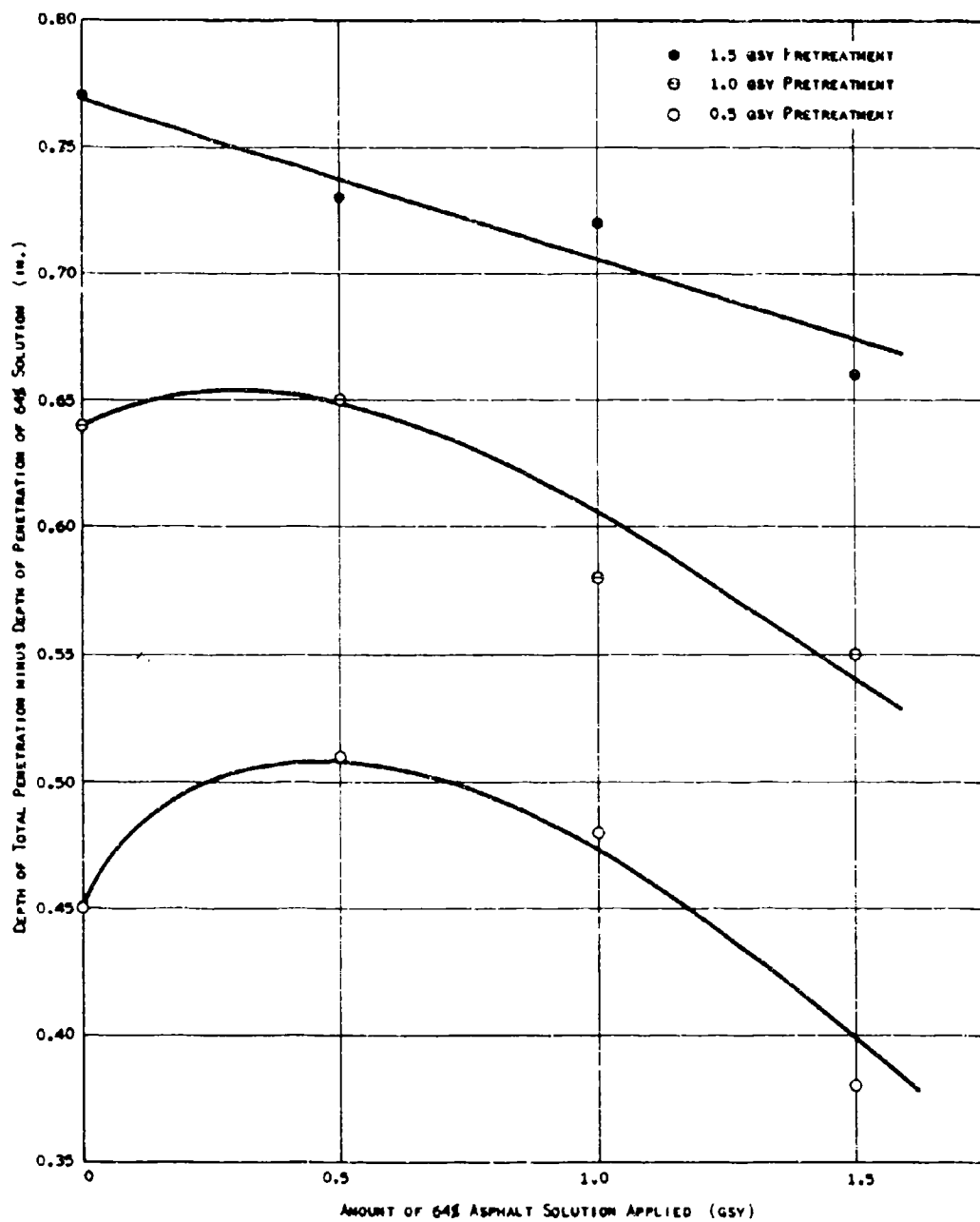


FIG. 4 - EFFECT OF RATE OF APPLICATION OF 64% ASPHALT SOLUTION ON TOTAL DEPTH OF PENETRATION

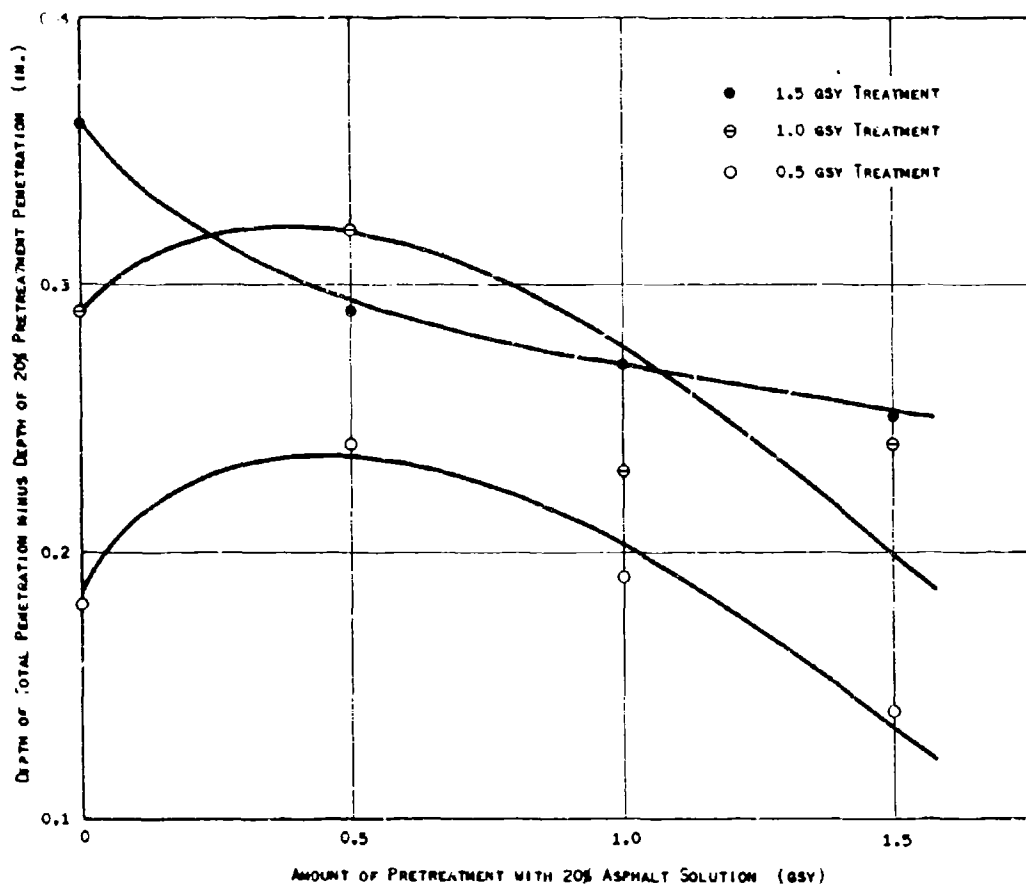
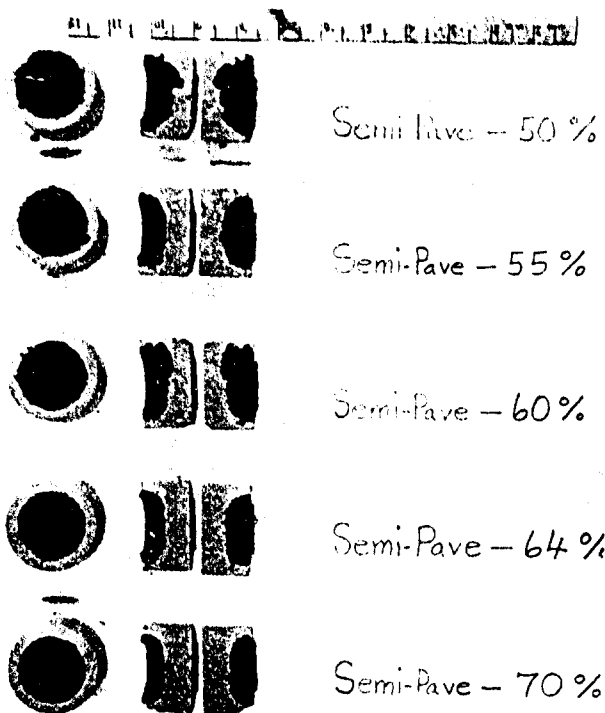
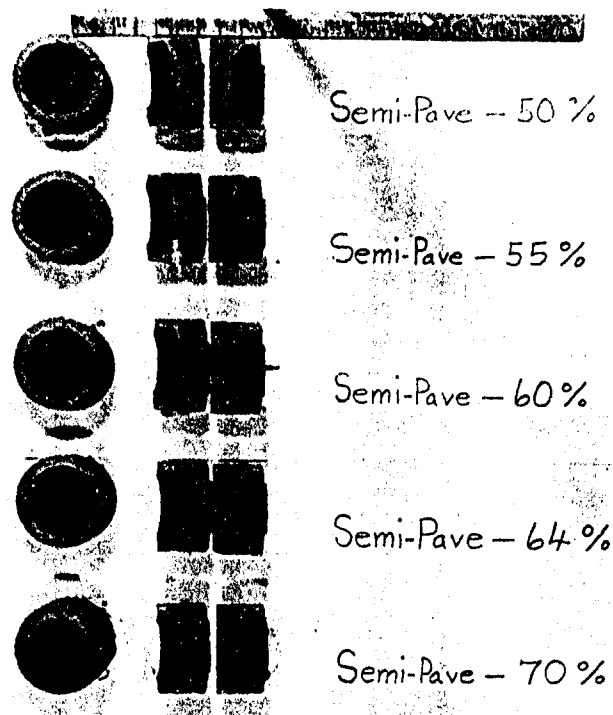


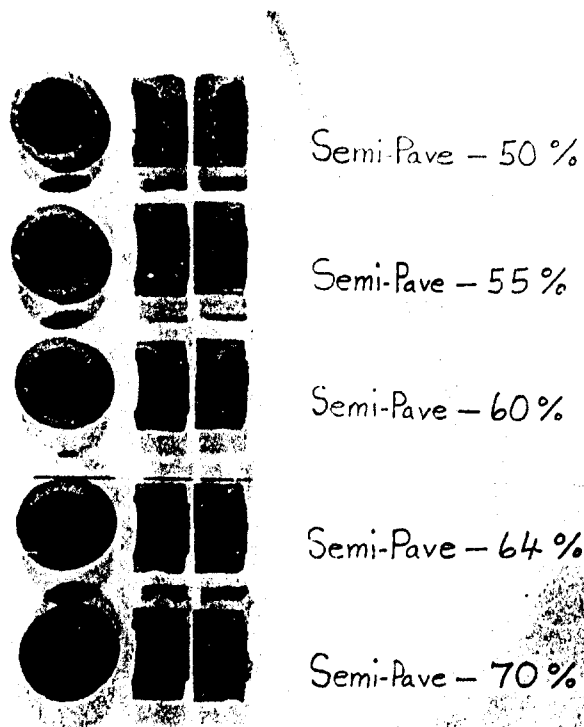
FIG. 5 - EFFECT OF QUANTITY OF PRETREATMENT ON DEPTH OF PENETRATION OF 6% ASPHALT SOLUTION



Pretreatment:  
Control None

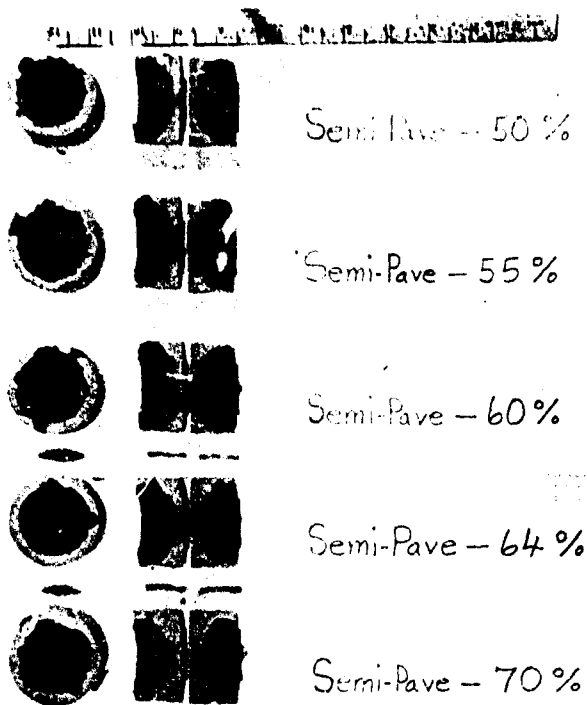


Pretreatment:  
Water

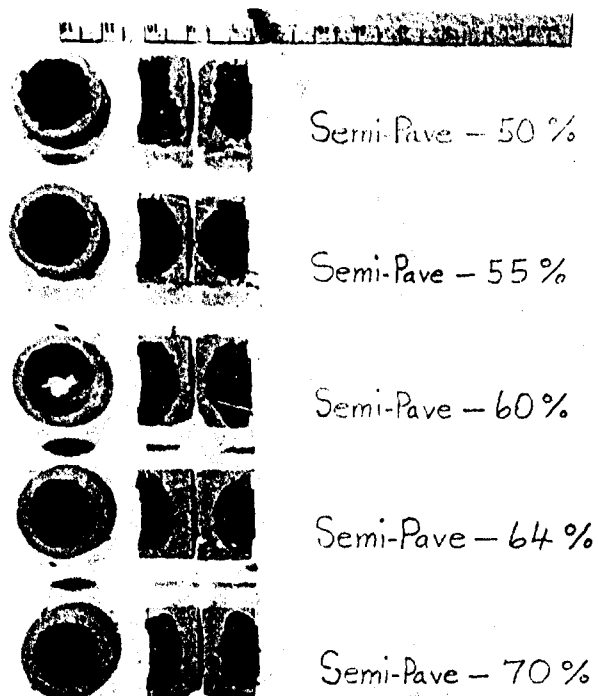


Pretreatment:  
Water + 0.5 % Anionic

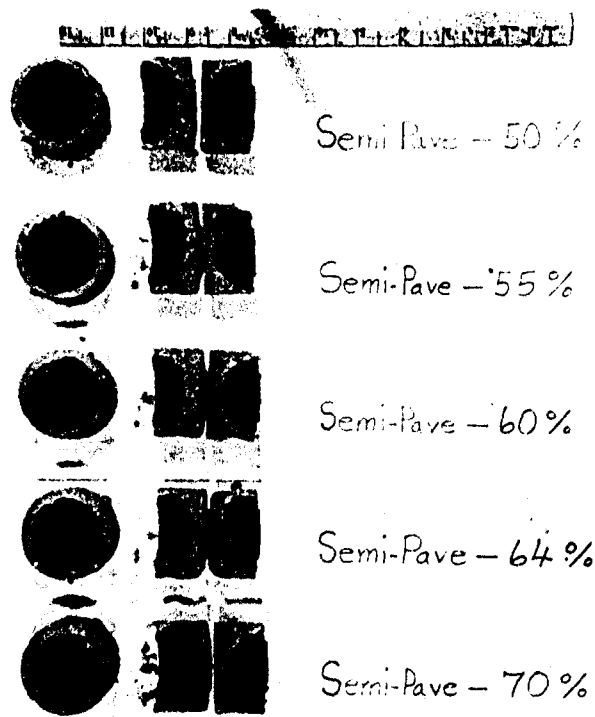
FIGURES 6, 7, and 8  
INFLUENCE OF PRETREATMENT  
ON PENETRATION



Pretreatment:  
Semi-Pave - 20 %



Pretreatment:  
Semi-Pave - 40 %



Pretreatment:  
Semi-Pave - 50 %

FIGURES 9, 10 and 11  
INFLUENCE OF PRETREATMENT  
ON PENETRATION

APPENDIX I

TABLES A-I through A-V  
and  
FIGURES A-1 through A-3



TABLE A-I. PUBLISHED INFORMATION ON TWO PETROLEUM RESINS

Physical Characteristics	Califlux GP	Califlux 550
Initial boiling point (°C at 10 mm Hg)	160	above 200
Flash point, COC	above 250°C (482°F)	above 250°C (482°F)
Mixed aniline point*	33.5°C	32.5°C
Viscosity at 25°C, cP at 90°C, cP	12,000 30	>100,000 180
Specific gravity	1.02	1.04
Chemical Composition, %		
Saturated hydrocarbons (P)**	10.8	6.9
Unsaturated hydrocarbons		
Group I (A <sub>1</sub> )**	15.5	18.9
Group II (A <sub>2</sub> )**	55.0	47.1
Nitrogen bases (N)**	18.7	27.1

\*50:50 dilution with n-heptane

\*\*Current names of fractions:

P = Paraffins  
A<sub>1</sub> = First acidaffins  
A<sub>2</sub> = Second acidaffins  
N = Nitrogen bases

TABLE A-11. DESCRIPTION OF POLYMERS

Designation	Type	Supplier
Acrylene 45	Modified acrylic latex	Chemical Div., Goodyear Tire & Rubber Company
Chemikum N-615 latex	NBR latex, high nitrile, 43 ML-4	Chemical Div., Goodyear Tire & Rubber Company
Comar MH 2 <sup>1</sup>	Coumarone-indene resin	Allied Chemical Corporation
Dow Latex 2647	Acrylic latex	Dow Chemical Company
Dow Resin PS-2	Poly(styrene) ~ 20,000 MW	Dow Chemical Company
Dow Resin PS-3	Poly(styrene) ~ 30,000 MW	Dow Chemical Company
Foral 85	Ester resin	Hercules Incorporated
Hycar 1441	NBR, high nitrile, 75-90 ML-4	B. F. Goodrich Chemical Company
Hycar 1442	NBR, med. nitrile, 75-90 ML-4	B. F. Goodrich Chemical Company
IR-700	IR, poly(isoprene) from latex	Shell Chemical Company
Kraton 101	SBR, thermoplastic block copolymer	Shell Chemical Company
Kraton 102	SBR, thermoplastic block copolymer	Shell Chemical Company
Liquid SBR Y335	SBR, low MW	Chemical Div., Goodyear Tire & Rubber Company
Natural rubber	NR, No. 1 ribbed smoked sheets	Harwick Standard Chemical Company
Natural rubber latex	NR latex	American Latex Corporation
Neoprene Latex 571	CR latex	E. I. duPont de Nemours & Company, Inc.
Neoprene MHV	CR, high MW	E. I. duPont de Nemours & Company, Inc.
Neville Resin R-16	Coumarone-indene resin, S.P. 94-107°C	Neville Chemical Company
Parlon	Chlorinated natural rubber	Hercules Incorporated
Pliolite 1502 latex	SBR latex, med. MW, 51 ML-4	Chemical Div., Goodyear Tire & Rubber Company
Pliolite 5352 latex	SBR latex, high MW, 100 ML-4	Chemical Div., Goodyear Tire & Rubber Company
Pliolite Resin Latex 460	Carboxylic modified SBR latex	Chemical Div., Goodyear Tire & Rubber Company
Pliolite Resin Latex 480	Carboxylic modified SBR latex	Chemical Div., Goodyear Tire & Rubber Company
Pliolite Resin Latex 491	Carboxylic modified SBR latex	Chemical Div., Goodyear Tire & Rubber Company
Pliolite Resin Latex 610	Carboxylic modified SBR latex	Chemical Div., Goodyear Tire & Rubber Company
Pliopave L-165-K	SBR cationic latex	Chemical Div., Goodyear Tire & Rubber Company
Plavox 300 Latex	Poly(vinylchloride) copolymer latex, med. MW	Chemical Div., Goodyear Tire & Rubber Company
Rhoplex AC-32	Acrylic resin emulsion	Robm & Haas Company
S-1502	SBR, med. MW, 50 ML-4	Shell Chemical Company
Thermelastix 125	SBR, thermoplastic block copolymer	Shell Chemical Company
Vistanex LN MH	Poly(isobutylene) ~ 9,000 MW	Enjay Chemical Company
Vistanex MSL-100	Poly(isobutylene) ~ 90,000 MW	Enjay Chemical Company

TABLE A-III. IDENTIFICATION OF TEST SOILS

Soils	Unified Class.	Plasticity LL PL PI	pH*	Surface Area cm <sup>2</sup> /g**	Oil Abs.†	Oil to Dust Free††	Specific Gravity	Wetting Characteristics
Illite	CH	53 28 25	4.1	12,900	33.4	14.7	2.82	Lipophilic
Pittsburg clay	CL	34 22 12	8.4	5,620	8.2	1.4	2.78	Hydrophilic
Antioch sand	SP	Non-plastic	5.6	178	4.5	0.96	2.73	Lipophilic

\* ASTM D-1208-52T, Electrometric Method.

\*\* Calculated by assuming each fraction is composed of spheres whose diameter is the mean of each fraction, applying formula for area of a sphere ( $\pi D^2$ ) x soil fraction corrected for density and adding all areas. Diameter: below 0.001 mm (limit of analysis) assumed to be 0.001 mm.

† Oil absorption ASTM D1483-57T.

†† Oil to dust-free condition, lb/100 lb, determined in Brabender pug-mill at 126 rpm, adding oil until agglomeration of particles caused increase in bulk volume.

TABLE A-IV. DESCRIPTION OF PETROLEUM BASED RESINOUS SOLVENTS USED IN DUST CONTROL STUDIES

Designation	General Description	Physical and Chemical Characteristics								Supplier	
		Initial Boiling Point, °C	Flash Point, °F COC	PMCC	Viscosity, cS 77°F 100°F 210°F	Chemical Composition, % N A1 A2 P					Specific Gravity
Califlux GP	Rubber extender oil, medium unsaturation, (I.N., HdbI, ca. 40)	Above 160 @ 10 mm Hg	440	-	9,000 1,520 19	18.7	15.5	55.0	10.8	1.01	Golden Bear Oil Co.
Califlux 550	Rubber extender oil, medium unsaturation (I.N. HdbI, ca. 45)	252 @ 10 mm Hg	475	-	750,000 80,000 97	28.0	23.0	40.0	9.0	1.03	Golden Bear Oil Co.
Philrich S	Rubber extender oil, medium unsaturation	-	480	-	30,400 - 75	13.1	14.9	60.7	11.3	0.98	Phillips Petroleum Co.
SR Stock	Heavy lubricating oil distillate, low unsaturation (I.N., HdbI, ca. 25)	Above 160 @ 10 mm Hg	485	-	7,000 1 650 31	14.6	14.3	35.4	35.7	0.96	Golden Bear Oil Co.
White oil, 350 SSU, 100°F	Mineral oil, highly refined, saturated	-	-	-	1.1 76 10	0.0	0.0	1	99	0.99	Standard Oil Co. of Calif.
GN-104	Nitrogen bases concentrate from Gilsonite	226 @ 760 mm Hg	-	220	158 -	91.1	4.2	<del>2.4</del>	<del>2.4</del>	1.01	American Gilsonite Co.
CTLA	Rubber reclaiming oil, highly unsaturated (I.N., WJs, 255)	-	230	-	- 29	37.6	38.9	19.8	0.3	1.00	Enjay Chemical Co.
SP 220	Rubber reclaiming oil, highly unsaturated (I.N., WJs, 175)	-	300	-	- 14	38.7	43.5	11.8	2.7	1.05	Enjay Chemical Co.

\* GN-104 also contained 2.3% insoluble in pentane; CTLA contained 3.4% volatiles and trace insoluble; RP 220 contained 3.3% volatiles and trace insoluble

TABLE A-V. DESCRIPTION OF MISCELLANEOUS PROPRIETARY PRODUCTS

Designation	General Description	Supplier
AgeRite Spar	Mono-, di- and tristyrenated phenols (antioxidant)	R. T. Vanderbilt Company, Inc.
Bitumuls SS-lh	Emulsion of paving asphalt	Chevron Asphalt Company
Oronite Dispersant NI-W	Nonionic surfactant	Chevron Chemical Company
Penepriime (Product A)	Special cut-back asphalt	Empire Petroleum Company
Redicote 2323	Cationic anti-stripping additive for asphalt	Armour Industrial Chemical Company
Redicote E-1	Tallow diamine (+ acetic acid = cationic surfactant)	Armour Industrial Chemical Company
Semi-Pave (Product C)	Special cut-back asphalt	Golden Bear Oil Company
Triton X-200	Sodium alkylaryl polyether sulfonate (anionic surfactant)	Rohm & Haas Company

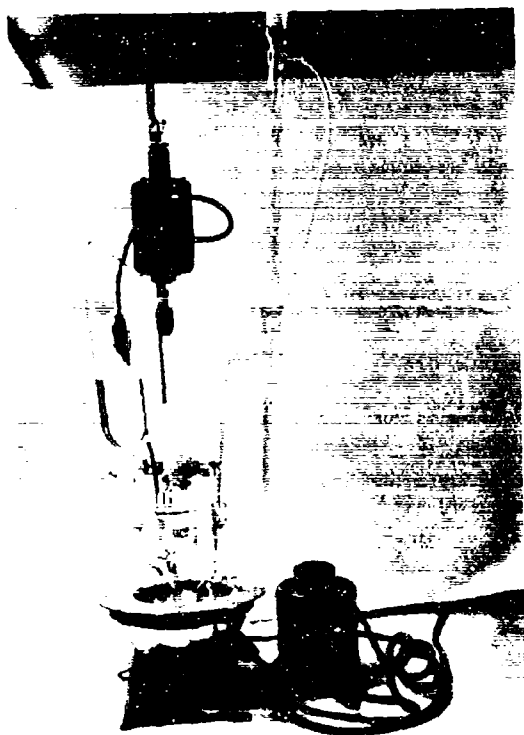


FIGURE A-1

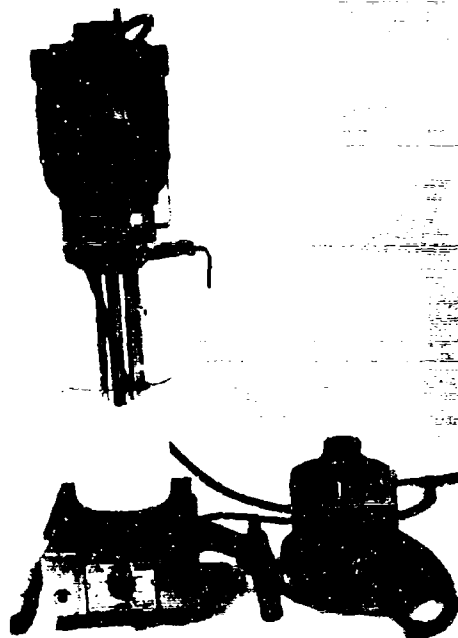
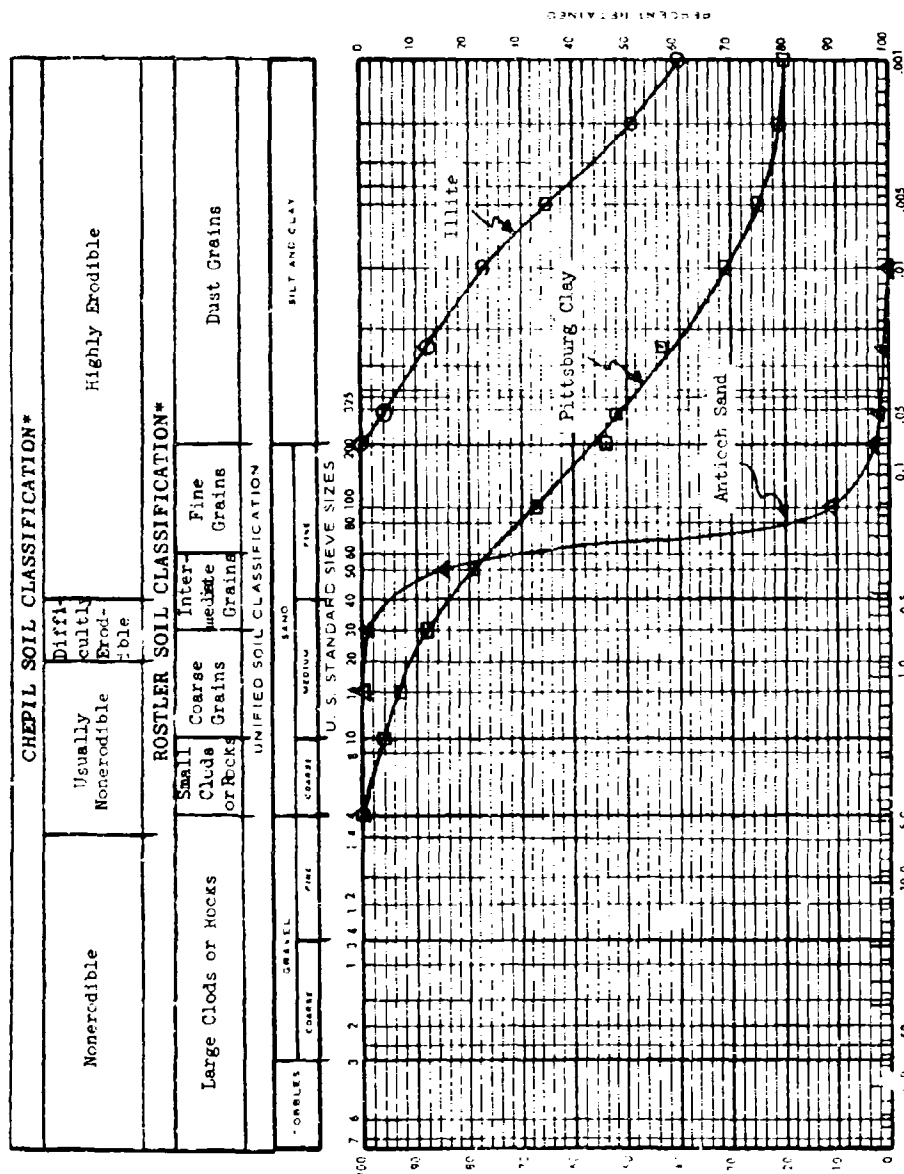


FIGURE A-2

LABORATORY ASSEMBLY FOR MAKING POLYMER SOLUTIONS

FIGURE A-3. IDENTIFICATION OF TEST SOILS



\*See Ind. and Eng. Chem., 56 (4), 27-33 (April 1964).

APPENDIX II

TEST METHODS  
and  
FIGURES A-4 through A-10



TEST METHOD 1  
SOIL PREPARATION FOR TESTS  
OF WIND AND WATER EROSION RESISTANCE

Scope

1. This method describes procedures for application of test materials to soil for subsequent testing of cohesiveness as measured by wind and water erosion tests. Method 1A is used for mixing the treating material with the soil; Method 1B for applying the treating material to undisturbed specimens. Method 1A is especially applicable to nonplastic soils; Method 1B may be used for any soils.

Method 1A

Apparatus

2. (a) Containers for holding and mixing 18 cu. in. of soil. Plastic containers 3 in. x 4 in. x 2 $\frac{1}{4}$  in. sold for refrigerating foods have been found satisfactory.
- (b) Graduated cylinders, 25, 50 and 100 ml.
- (c) Spatulas, flexible stainless steel with wooden handle, blade 11/16 in. x 4 in.
- (d) Interval timer with second hand.
- (e) Spray device as shown in Figure A4.
- (f) Forced-circulation oven capable of maintaining a temperature of 130  $\pm$  5 F.
- (g) Sieve, U.S. Standard No. 16.

Procedure

3. (a) Preparation of Specimens--Sieve soils to be used in test through a No. 16 sieve, discarding the plus-16 mesh fraction. Measure 18 cu. in. of test soil into container. The soil may be measured in its loose dry state by volume or weight equivalent. Level the surface of the soil by shaking lightly in the horizontal plane; avoid compaction of the test soil.

(b) Application of Test Material--Pour or spray the amount of material to be tested rapidly over the surface of the test soil. Record the penetration time from start of application to disappearance of liquid from the soil surface.

(c) As soon as penetration is complete, mix the test soil and treating material thoroughly to wet all of the soil. Place the uncovered container of soil in the forced air oven for 18 hr. Remove from the oven, mix the soil thoroughly and return it to the oven for an additional 2 hr. Remove from the oven, mix thoroughly, cover and allow to cool to ambient temperature before testing.

#### Method 1B

#### Apparatus

4. (a) Specimen holders, plastic or metal, 4 in. x 4½ in. x 1¼ in. deep, with a removable strip ½ in. x 3 in. cut from the top edge of one 4-in. side. For compacted specimens use the metal containers with the strip clamped in place; for uncompacted specimens the removable strip may be held in place with pressure-sensitive tape.

NOTE: Removal of this strip during erosion testing reduces the effects of extraneous eddy currents during wind erosion tests and hydrostatic pressure during water erosion tests.

(b) Graduated cylinders, 25, 50 and 100 ml.

(c) Spatulas, flexible stainless steel with wooden handle, blade 11/16 in. x 4 in. long.

(d) Interval timer with second hand.

(e) Spray device as shown in Figure A4.

(f) Forced-circulation oven capable of maintaining a temperature of 130 ±5 F.

(g) Paper-backed pressure sensitive tape, ½ in. wide (masking tape).

(h) Sieve, U.S. Standard No. 16.

## Procedure

5. (a) Preparation of Specimens--Sieve soils to be used in test through a No. 16 sieve, discarding the plus-16 mesh fraction. Fill container, with removable section in place, level full with or without compaction, as specified. Use metal containers with the removable strips clamped in place for compacted specimens. Around the top edge of the container place a strip of paper-backed tape as a dam so that it extends about  $\frac{1}{4}$  in. above the top edge of the container. The tape dam holds the liquid test material while penetration is taking place.

(b) Application of Test Material--Pour or spray the amount of material to be tested rapidly over the surface of the test soil. Record the penetration time from the start of application to disappearance of the liquid from the surface.

(c) As soon as penetration is complete, remove the strip of paper-backed tape to allow air movement across the surface of the treated soil. Dry the sample, without disturbing the surface, at ambient temperature or in oven at elevated temperature for specified time before testing (see note). Remove the cut-out section of the container before subjecting the specimen to erosion tests.

NOTE: Temperature should not exceed 140 F, time of drying to be specified on basis of experience to reach constant weight. Oven drying should not be used when treating agents cure by chemical reaction.

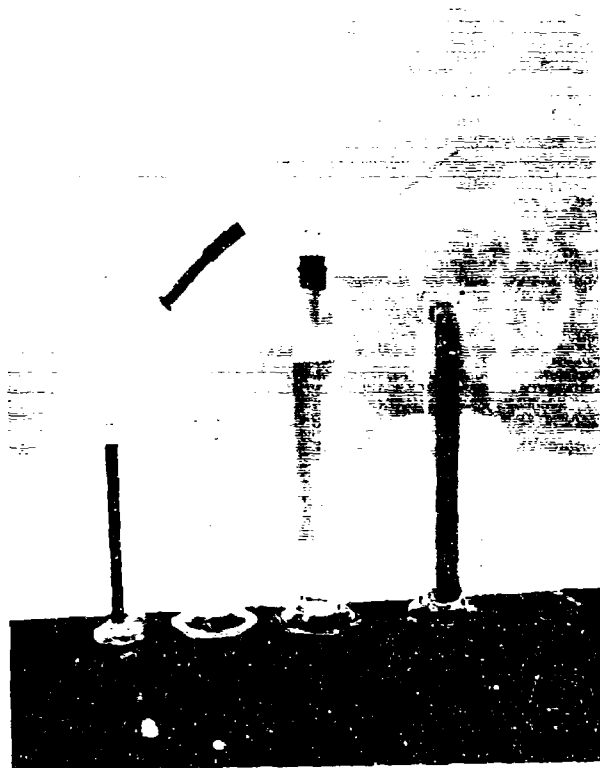


FIGURE A-4

SPRAY DEVICE FOR APPLICATION OF TEST MATERIALS

## TEST METHOD 2

### RESISTANCE OF TREATED SOILS TO WIND EROSION

#### Scope

1. (a) This method describes procedures for measuring the relative resistance to erosion by wind of soils and is used for evaluating the cohesiveness or binding quality imparted by use of soil treatments. Application is limited to specimens wherein the predominant particle size is not greater than 2 mm (10 mesh) and with no particles larger than 4.76 mm (4 mesh).

(b) Two procedures are given: Method 2A, for uncompacted mixed soils described in Test Method 1A and Method 2B for undisturbed treatments of compacted or uncompacted soils described in Test Method 1B. Method 2B is patterned after the testing procedure described in Corps of Engineers' Report WESSS3 (Reference 13).

(c) The equipment used is compact, simple and inexpensive. Figure A5 and Figure A6 show the apparatus in calibrating and in testing position, respectively, for Method 2A, and Figure A7 and Figure A8 show it in calibrating and testing position for Method 2B. Maximum wind velocities attainable are 170 mph with the Method 2A apparatus and over 230 mph with the Method 2B apparatus.

#### Apparatus

2. (a) Blower assembly constructed by mounting on a plywood box, four twin turbine blower units driven by universal motors (household vacuum cleaner units) with a metal tube fitting or hose attachment to take a 1½ in. diameter vacuum hose, tightly sealed to outlet hole in one end of the box. The blower assembly is shown in Figures A5 through A8.

(b) A heavy duty variable transformer, 25 ampere capacity to control voltage input to the blowers.

(c) A 12 in. length of 1½ in. diameter household vacuum cleaner hose with adapter to fit blower attachment at one end and a 1¼ in. adapter on the output end.

(d) For Method 2A, a miniature wind machine as shown in Figures A5 and A6 constructed from wood as a square tube, 12 in. long having an internal cross-section 1 in. square with two aluminum flow-straightening grids made from thin 1 in. long sheets placed  $\frac{1}{4}$  in. apart and fitted into the tube during construction; one end constructed to accept the  $1\frac{1}{4}$  in. adapter of the hose from the blower box and the other end fitted with a thin stainless steel sheet extending 2 in. beyond the bottom end to minimize eddy currents from the air stream.

(e) For Method 2B, a tapered nozzle with adjustable angle mounting shown in Figures A7 and A8. This nozzle is a small-scale version of the test nozzle used by the U.S. Army Corps of Engineers. The nozzle is connected to the blower assembly using the hose specified above.

(f) Air speed indicator with pitot tube (for calibration only).

(g) For Method 2A, specimen holders for testing mixed uncompacted soils (Method 1A) constructed by cutting a 13 in. radius concave surface on the face of a clear block of wood, 1-15/16 in. wide, 1-7/16 in. high, and 6 in. long, with sides of thin sheet metal, 1-7/16 in. high and 6 in. long, stapled or tacked to the sides of the base block.

(h) For Method 2B, specimen holders, plastic or metal, 4 in. x 4 $\frac{1}{2}$  in. x  $1\frac{1}{4}$  in. deep, with a removable strip  $\frac{1}{2}$  in. x 3 in. cut from the top edge of one 4 in. side. For uncompacted specimens the removable strip may be held in place with pressure-sensitive tape; for compacted specimens use the metal containers with the strip clamped in place.

NOTE: Removal of this strip during erosion testing reduces the effects of extraneous eddy currents during wind erosion tests and hydrostatic pressure during water erosion tests.

### Calibration

3. Wind speed should not be measured during testing of specimens as the pitot tube causes turbulence, which would interfere with maintaining uniform conditions of the tests. Calibration of airspeeds corresponding to voltages is made with pitot tube placed at a distance of 2 in. from the outlet end of the wind tunnel or angle nozzle as shown in Figures A5 and A7. The voltage readings are used during testing to record wind velocity. The unit should be recalibrated periodically,

particularly if large changes in ambient temperature occur. Unless a constant voltage power supply is available, a voltmeter should be used for calibration rather than the dial graduations of the transformer.

#### Method 2A

##### Preparation of Specimens

4. (a) Pour loose soil or soil treated as described in Method 1A into specimen holder in excess of the amount required. Strike off the excess by rolling a  $\frac{1}{4}$  in. rod from one end to the other of the specimen holder.

(b) Place the filled specimen holder longitudinally under the metal strip at the outlet end of the wind machine. Adjust the wind machine so that the metal shelf is flush and level with the surface of the test specimen.

##### Procedure

5. (a) Subject the specimen to wind velocities in 10 mph increments starting at 40 mph using voltages determined by previous calibration. Maintain each increment of wind velocity for 30 sec or until failure occurs. Record wind velocity at which the first visual loss occurs and that at which the soil is blown away to the extent that the center of the specimen holder becomes exposed.

(b) Report the range of minimum-to-maximum wind velocities at which loss occurred as wind erosion resistance in miles per hour. Note any unusual behavior such as large pieces being blown away.

#### Method 2B

##### Preparation of Specimens

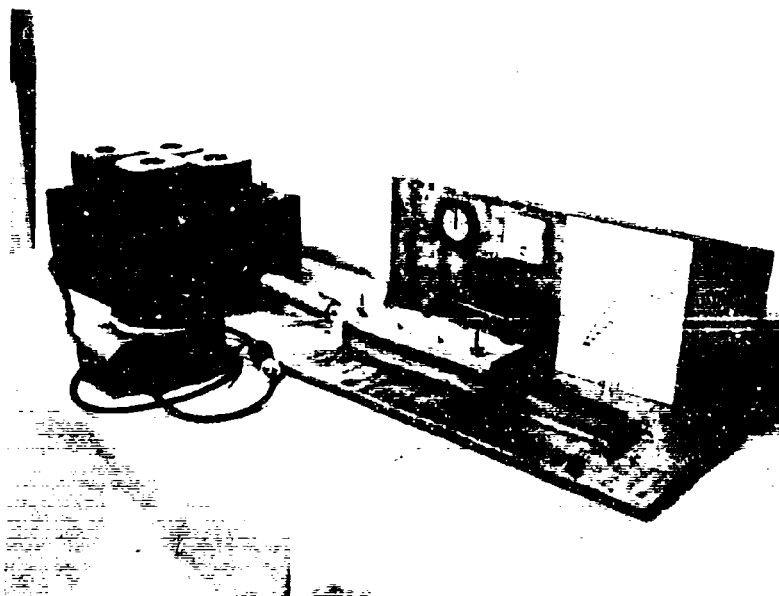
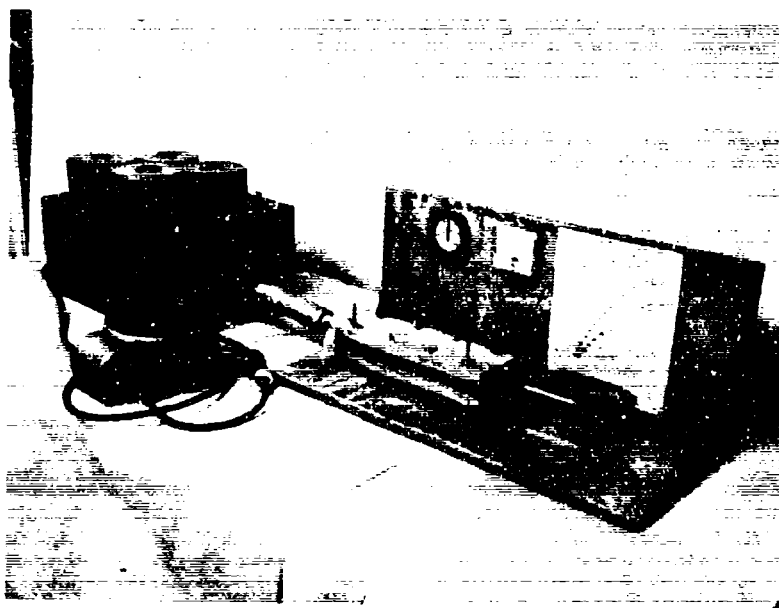
6. (a) Prepare specimens as described in Method 1B for undisturbed compacted or uncompacted soils.

(b) Adjust angle nozzle, set at an angle of 20 deg from horizontal, so that the outlet end of the nozzle is 2 in. from the point of impingement at the center of the surface of the test specimen.

##### Procedure

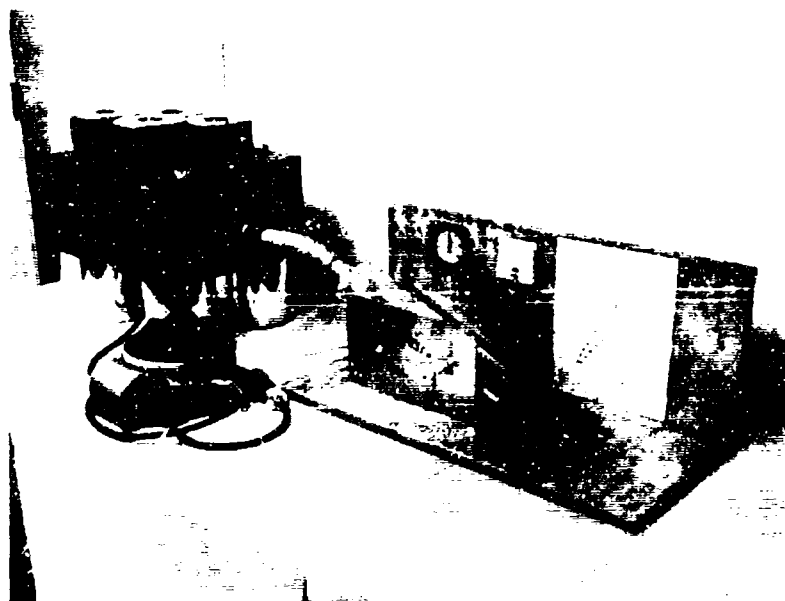
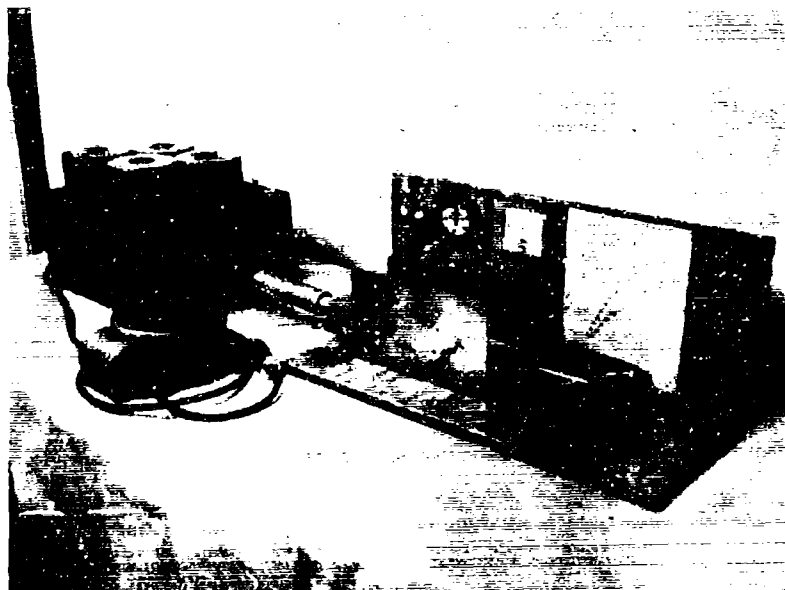
7. (a) Subject the test specimen to wind velocities of 50, 100 and 150 mph, holding for 1 min at each velocity. If the sample is unharmed at these velocities increase to maximum available wind velocity.

(b) Report any loss or failure in terms of the time the specimen survived at that velocity.



FIGURES A-5 AND A-6  
CALIBRATION AND USE OF MINIATURE WIND MACHINE--METHOD 2A





FIGURES A-7 AND A-8  
CALIBRATION AND USE OF MINIATURE WIND MACHINE--METHOD 2B

### TEST METHOD 3

#### RESISTANCE OF TREATED SOILS TO WATER EROSION

##### Scope

1. This method describes a procedure for measuring the relative resistance of treated soil to erosion by simulated heavy rainfall, and the cohesiveness and binding quality of the soil treatment under these conditions. The equipment used is compact, simple and inexpensive and was designed to approximate the conditions used by the U.S. Army Corps of Engineers Waterways Experiment Station. Two procedures are used: Method 3A, for uncompacted mixed soils, prepared as described in test Method 1A, and Method 3B for undisturbed compacted or uncompacted soils prepared as described in Method 1B.

##### Apparatus

2. (a) Spray apparatus as shown in Figures A9 and A10 consisting of:

a circular turntable driven by a small electric motor at 6 rpm,

a perforated spray head (Ross No. 10 garden sprinkler head with 0.032 in. diameter holes, blanked off except for 39 holes in 3 rows of 13 each) positioned 18 in. above the turntable and connected to a reservoir maintaining a 6 in. head of water above the spray outlet,

a transparent plastic shield to enclose the apparatus and confine the water splash, and

a drain reservoir beneath the turntable to collect the run-off.

(b) For Method 3A, specimen molds 2-3/8 in. in diameter by 1/2 in. deep (aluminum foil weighing dishes).

(c) Spatulas, flexible stainless steel with wooden handle, blade 11/16 in. x 4 in.

(d) Interval timer.

##### Method 3A. Water Erosion of Noncompacted Soil

##### Preparation of Specimens

3. Pour treated soil, prepared as described in Method 1A, into the specimen mold in excess of the mold capacity. Pack lightly to maintain specimen shape and

strike off the excess soil. Place a 3 in. square of thin cardboard (e.g., manila folder stock) on top of the specimen mold, invert and gently slide the specimen from the cardboard onto the turntable, and remove the mold.

#### Procedure

4. (a) Place the specimens to be tested onto the turntable, as described in preparation and shown in Figure A9. The turntable can be loaded to its capacity, but do not place specimens within 2 in. radius of the center of the table. Start turntable and turn on water spray.

(b) Record as "percent remaining" visual estimate of soil sample remaining intact at 10, 20 and 60 minutes and record time of total erosion of sample, if it occurs.

#### Method 3B. Water Erosion of Treated, Undisturbed Soil Specimens

#### Preparation of Specimens

5. Use specimens prepared as described in Method 1B.

#### Procedure

6. (a) Place the containers with undisturbed treated soil on the turntable as in 4(a) above and shown in Figure A10. Start the turntable and turn on the water spray. Test the specimen for a period of 1 hr or until complete erosion of the surface occurs.

(b) Record behavior such as skin separation or forming of bubbles. Record time to total erosion or estimate of erosion extent after 1 hr as "percent remaining."

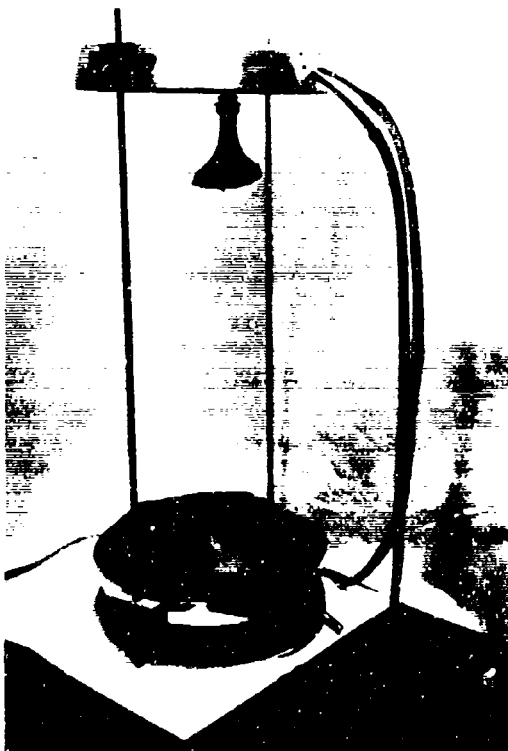


FIGURE A-9

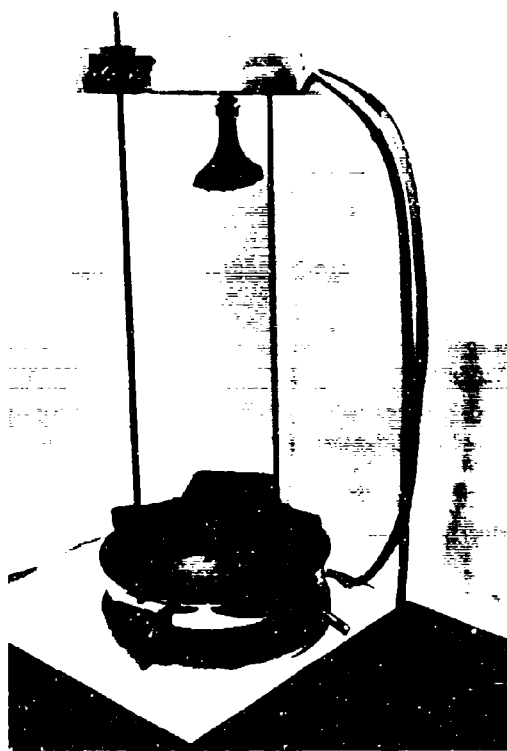


FIGURE A-10

SPRAY APPARATUS FOR METHODS 3A AND 3B  
(Plastic Shield Removed)

TEST METHOD 4  
WIND AND WATER EROSION TEST OF TREATED SOIL

Scope

1. This method describes the test procedure used in the dust control studies to approximate the methods used by the U.S. Army Corps of Engineers Waterways Experiment Station at Vicksburg, Mississippi. This method incorporates Methods 1B, 2B, and 3B in the sequence used.

Procedure

2. Subject treated soil samples prepared as described in Method 1B to wind erosion tests as described in Method 2B. If the sample does not fail in the wind erosion test, immediately subject it to the water erosion test, Method 3B. If the sample passes the water erosion test, immediately subject it again to the wind erosion test, Method 2B. If the sample again passes the test, dry it 16-20 hr at ambient temperature and 1 hr under an infra-red heat lamp at a soil surface temperature of 125 F and again subject the specimen to the wind erosion test, Method 2B.

TEST METHOD 5  
TEST FOR PENETRATION AND QUALITY  
OF SOIL TREATMENTS

Scope

1. This method describes the screening procedure used in testing the penetration rate and a visual qualitative evaluation of soil treatments on various test soils.

Apparatus

2. (a) Graduated cylinders, 10 and 25 ml.
- (b) Aluminum foil dishes, 2-3/8 in. diameter, 1/2 in. deep.
- (c) Cork or rubber stoppers approximately 4 cm in diameter.
- (d) Small bubble level, e.g., a 4 in. aluminum level.
- (e) Interval timer with second hand.

Procedure

3. (a) Fill an aluminum dish about 3/4 full with the soil to be tested. Make a level depression 1/8 to 1/4 in. deep into the soil using the cork or rubber stopper and turning it with light pressure so as not to compact the soil. Check the level by placing the bubble level across the top of the cork, north to south and east to west.
- (b) Pour 4 ml of test material into the depression and time the penetration from initial application to disappearance of liquid from the surface.
- (c) Record penetration time and rate as follows:
  - 1 = 1 minute or less
  - 2 = 1-5 minutes
  - 3 = 5-30 minutes
  - 4 = more than 30 minutes
  - 5 = no penetration
- (d) After allowing treated sample to dry for 24 hr, rate the quality of the treated soil surface or the deposited skin using appropriate descriptive terms from the following list:

Oily, sticky, tacky, dry  
Liquid, soft, firm, hard  
Weak, strong  
Flexible, brittle

(e) Split or break the sample and record depth of penetration and the presence of layers, if any are visible.

TEST METHOD 6  
TEST FOR PENETRATION OF LIQUIDS INTO SOIL

Scope

1. This method describes a test used for measuring the rate and depth of penetration of liquids into soil specimens molded by double-end compaction. Soil such as silty sand (U.S. Army Corps of Engineers Unified Soil Classification, Type SM) is suitable for evaluating most soil-treatment liquids; finer grained soil may be used for liquids with exceptionally good penetration properties.

Apparatus

2. (a) Soil specimen (briquet) mold consisting of the following parts:
  - a steel cylinder 2.01 in. inside diameter and 3.0 in. high,
  - a steel insert 2.00 in. in diameter and 1.250 in. high with a 0.250 in. additional length machined to leave a 2.0 deg tapered protrusion 1.128 in. in diameter at the end (1 sq in. cross section),
  - a steel piston 2.00 in. in diameter and 2.00 in. high, and
  - three steel spacer blocks made of 0.250 in. square key stock 1.0 in. long.
- (b) Carver Laboratory press.
- (c) Sieve, U.S. Standard No. 16.
- (d) Metal pans, 9 in. x 13 in. x 2 in. (baking pans).
- (e) Pipettes.
- (f) Graduated cylinders, 10 ml, 25 ml.
- (g) Spatulas, flexible stainless steel with wooden handle, blade 11/16 in. x 4 in.
- (h) Small scoop or large spoon.
- (i) Balance, accurate to 0.01 g.
- (j) Interval timer with second hand.



### Preparation of Soil

3. Sieve soil through a No. 16 sieve, discarding the plus-16 mesh fraction. Adjust moisture content of soil to the content required for optimum compaction and store in a covered container for 24 hr before using.

### Preparation of Test Specimens (Sandy Soil)

4. (a) Place the mold insert inside the mold cylinder with the flat side on the lower platen of the Carver press. Raise the cylinder and support it at a height of 1 in. with the steel blocks. Place 90 g of soil in the raised cylinder and insert the piston. Apply pressure until the pressure indicator first registers. Release the pressure and remove the support blocks. Apply pressure again to 1885 lb, equivalent to 600 psi on the specimen, and hold for 1 min.

(b) Invert the mold, block the cylinder at the top with the metal blocks and apply pressure to extrude the compacted specimen from the mold. Rotate the mold insert to loosen it before removing it from the specimen. Place the specimen in a metal pan to dry at ambient temperature before testing.

### Procedure

5. (a) Introduce into the depression of the specimen the amount of soil-treatment material to be tested, by pouring, weighing, or using a pipette, as appropriate for the material used.

NOTE: 2.92 ml is equivalent to 1 gal/yd<sup>2</sup> and 0.35 g is equivalent to 1 lb/yd<sup>2</sup>.

(b) Record time from initial application until the liquid disappears from the surface. Record any unusual effects observed (e.g. swelling of soil, rapid breaking of emulsion, etc.)

### Inspection of Treated Specimen

6. (a) After penetration is complete (or after a specified drying or curing time), split and examine the specimen by placing a heavy knife or cleaver across the center of the specimen and striking it a sharp blow with a hammer or by sawing the specimen across the center with a thin saw blade.

(b) Measure and record the depth of penetration. Report any layer separation that is apparent and the depth of each layer.

**APPENDIX III**  
**UNPUBLISHED REFERENCES**

OBSERVATIONS ON SOME SOIL STABILIZATION  
WORK IN CALIFORNIA

W. S. Chepil, May 31, 1960

This is a brief report of the impressions gained from observing the soil stabilization programs carried out by the Golden Bear Oil Company and the Edwards and Vandenberg Air Force Bases of California.

I was particularly impressed with a miniature wind tunnel and accessory equipment developed by Dr. F. S. Rostler of the Golden Bear Oil Company for testing wind erodibility of soil samples treated with various dust binders. Treatments consist of mixing measured quantities of binder of various degrees of dilution with measured quantities of loose, dry soil in which clods, if any, were broken down. A check consists of no treatment other than exposure of the same soil material to wind.

Wind tunnel tests on treated and untreated samples consist of two aspects of erodibility: (1) the threshold wind velocity required to initiate soil movement, and (2) the time required to remove the soil. The wind tests are relative, but some idea of wind force on the sample may be obtained by calibrating threshold wind velocities of standard soil materials in the miniature wind tunnel against threshold velocities in a larger tunnel, such as the one at Manhattan, Kansas, in which wind forces equivalent to what they would be in the field can be measured.

---

1/ For in-service use only. The contents of this report may not be published or reproduced in any form without prior consent of the research workers involved.

It is believed that the wind tests, as set up presently, exaggerate the effects of dust binders in some cases. Soils seldom are in a loose, pulverized condition even in the driest of climates. Even a gentle rain causes some cementation of the soil material and the formation of a surface crust which have considerable influence on erodibility by wind. A more equitable test, it is believed, would be to add water to the check sample in quantity at least equal to that contained in the dust binder, but preferably a quantity necessary to wet the soil clear through, drying both the check and the treatment, and then testing them for erodibility by wind. Wetting and drying is expected to have little influence on sand but a considerable influence on the finer-textured soil materials.

#### Land Stabilization at Edwards Air Force Base

The problem of wind erosion at this location is based on continual encroachment of sand from the surrounding desert onto an inhabited, urban community. The problem is intensified by clearing of desert vegetation, mostly creosote plant, within and surrounding the inhabited area. Average rainfall is somewhat less than 5 inches per year.

Wherever water is applied in ample quantity, almost any kind of vegetation suited to the arid atmosphere can be grown there. But, water is costly and much of the area within the town is bare and presents a serious dust problem. Most of the home sites are surrounded by high, solid fences to keep the wind and the dust down.

Despite the extremely severe natural conditions, the dust problem has been kept well under control. The following methods have been used

in the program of soil stabilization in the area:

1. Snow fences some distance away from the settlement are put up to trap most of the sand coming in from the outside.

2. A belt of trees is planted some distance inside the snow fences to slow down wind velocity and drop a load of finer dust. The trees have to be watered to stay alive. This is costly but extremely essential for reasonably comfortable existence within the settled community.

3. Lawns and gardens are maintained wherever possible by irrigation. However, much of the area within the town is not irrigated and therefore remains bare.

4. Virtually all bare areas within the town are stabilized against wind. Remarkable success has been achieved with the Golden Bear dust binder. The treated areas remain stable for at least several years unless fresh sand is allowed to encroach from the outside or tramping is heavy. In such cases, treatments repeated at intervals are necessary.

Some efforts were made to stabilize the soil with vegetative covers. A cereal crop was grown to supply the cover. The crop had to be irrigated to germinate and produce growth. Growth ceased soon after irrigation stopped. Decomposition of dead vegetative matter is extremely slow. The dead cover resulting from the crop grown 4 or 5 years ago still remains on the ground. In humid regions this would have disappeared in a few months.

Despite slow decomposition, establishment of vegetative cover with irrigation is extremely slow and expensive. Hauled-in vegetative

matter is also costly. The use of Golden Bear dust binder appears to have given the cheapest and most effective solution of the dust problem at that location.

#### Stabilization at the Vandenberg Air Force Base

This base is located on coastal sands. Prevailing winds blow from the ocean and continually supply fresh dune sand from the shore. The problem of sand blowing has been aggravated by road building, land levelling, etc., which destroys the natural protective cover on the land. Mean annual precipitation is about 11 inches which occurs mostly during the winter. Virtually no rain falls during June through September. Despite the tremendous quantities of sand to contend with, virtually all of the occupied area has been stabilized. The sand stabilization program consists of the following practices:

1. In areas next to the high water line, sand ridges about 2 feet high have been put up at regular intervals and the whole area treated with Golden Bear dust binder. The purpose of the ridges is to trap much of the sand that is blown in from the shore. As soon as the areas to the lee of the ridges are filled to capacity, new ridges are thrown up and stabilized with Golden Bear dust binder. Snow fences instead of sand barriers were tried but discontinued because the sand piles trapped between the fences were too high to be stabilized conveniently with the dust binder.

2. Dunes just slightly inland of the blown beach sands were planted to European beach grass (Holland grass). Any sand escaping from

the beach would be trapped by the grass. Beach grasses will continue to grow as dunes increase in height so long as the sand accumulation is not faster than growth of grass.

3. Australian veldt grass (an annual grass suited to sand) is planted on areas that are not subject to sand encroachment. It is an abundant seed produced and can propagate itself from seed indefinitely. Bare areas are stabilized with Golden Bear dust binder before seeding the grass. In some cases grass seedlings died as a result of whipping by wind. A vegetative mulch might have protected the seedlings, but difficulty was experienced in properly anchoring the mulch. A sheep's foot packer and a disk harrow were used to anchor the mulch.

4. Ice plant (*Mesembryanthemum roseum*, var. *edule*), a native of South Africa but especially adaptable to California, is planted on roadside banks, terraces, etc., where it is difficult to establish other vegetation. It is a fast-growing, trailing succulent plant which furnishes good ground cover for dry, exposed sites. It is used at this location, as in other parts of California, for protection of roadside banks.

5. Roadside banks are covered with vegetative mulch tied down with wire screening. Ice plant is then planted to serve as a permanent cover.

Attempts to establish trees without irrigation failed. Orzan (Turbosan) a byproduct of the paper pulp industry, was used to stabilize the sand but failed in at least one respect. Grass seeded before Orzan was applied failed to emerge. Apparently the material is toxic to plant

growth. The surface film resulting from spraying the material is extremely brittle and does not seem to have the tenacity of the Golden Bear dust binder on sand.



## EVALUATION OF A SMALL LABORATORY WIND MACHINE

R. M. White

Materials Research & Development, Inc.

### Introduction

Wind tunnels in use for measurement of soil erosion rates are quite bulky and unwieldy, requiring large power sources to supply the volumes of air needed to achieve working velocities in tunnels of large cross-section. The main reason given by designers of tunnels of large cross-section and long length is the need to minimize wall effects. A discussion of these effects has been presented by Zingg and Chepil (1) together with descriptions of several wind tunnels ranging in size upwards from Bagnold's 1- x 1- x 30-foot tunnel.

The tunnel constructed by Zingg and Chepil at Kansas Agricultural Experiment Station, based on their analysis of experience with previous tunnels, consists of a duct 3 feet square and 56 feet long, with air supplied by a fan driven by a 30 hp gasoline engine. Zingg (2) has also described a portable tunnel 3 feet square and 30 feet long using the same air supply system.

A miniature wind machine which avoids wall effects by using an unconfined air stream has been suggested and used by Rostler (3,4).

### Description of Miniature Wind Machine

Figure 1 is a schematic drawing and Figure 2 is a photograph of the apparatus. Wind velocities of up to 97 mph have been attained in this apparatus using a household vacuum cleaner blower unit as air supply. Employing the same equipment with four blower units in parallel, velocities of over 170 mph have been attained.

In addition to the obvious advantages of low equipment cost, low operating cost, and small space requirements, the miniature wind machine is especially useful for small scale tests evaluating the effectiveness of soil-treating materials without using large quantities of soil and of test material.

### Tests with Standardized Soils

Chepil suggested that the values obtained using the miniature apparatus be compared with values obtained in large wind tunnels to establish the feasibility of using the small scale laboratory wind machine in extended series of tests, where the use of large wind tunnels is impractical. Following Chepil's suggestion, erodibility by wind was measured, using the miniature wind machine and the shallow holders, on a series of seven synthetic soils used by Chepil in his work (5) and supplied by him for this study. The synthetic soils are artificial mixtures of dune sand with gravel 2 to 6.4 mm in diameter. Gravel is preferable to soil clods for calibration purposes since it is resistant to breakdown by handling.

Table I shows the data obtained with the miniature apparatus. In Figures 3 and 4 these data are graphed for comparison with the curve shown by Chepil in Figure 17 of Reference 5.

It can be seen from the data that up to erodibility of about five tons per acre, the erosion occurring during one to three minutes' exposure to an air stream of 20 mph constant velocity in the miniature apparatus can be correlated directly with the erosion of the same soil occurring with the large wind tunnel used by Chepil and coworkers. The values obtained with the miniature apparatus show a leveling off at erodibility greater than about 5 tons per acre, corresponding to the approach to total erosion of the shallow specimens. It is noteworthy that erodibility of five tons per acre is the level used by Chepil as a demarcation line between his ratings of "Moderate" and "High" erosion.

### Conclusion

Chepil's expectation has been shown to be correct that the miniature wind machine used by Rostler for establishing relative ratings of erodibility is a useful apparatus for screening tests, supplying values which can be correlated with those obtained in large tunnels and field tests.

#### LITERATURE REFERENCES

1. Zingg, A. W. and W. S. Chepil, "Aerodynamics of Wind Erosion," Agricultural Engineering 31, 279-284 (June, 1950); also published as Contribution No. 403 from the Department of Agronomy, Kansas Agricultural Experiment Station and the Soil Conservation Service, U.S. Dept. Agriculture.
2. Zingg, A. W., "A Portable Wind Tunnel and Dust Collector Developed to Evaluate the Erodibility of Field Surfaces," Agronomy Journal 43, 189-91 (April, 1951); also published as Contribution No. 424 from the Department of Agronomy, Kansas State College and the Soil Conservation Service, U.S. Dept. Agriculture.
3. Rostler, F. S. and W. M. Kunkel, Jr., "Soil Stabilization," Industrial and Engineering Chemistry 56, 27-33 (April, 1964).
4. Peters, John and Joe Sciandrone, "Stabilization of Sand Dunes at Vandenberg Air Force Base," J. Soil Mechanics and Foundation Div., Proc. A.S.C.E. 90, No. SM4, 97-106 (July, 1964).
5. Chepil, W. S., Soil Conditions that Influence Wind Erosion, Technical Bulletin No. 1185, U.S. Dept. Agriculture, Agricultural Research Service, in cooperation with Kansas Agricultural Experiment Station, Washington, D. C. (June, 1958).

TABLE 1. ERODIBILITY OF SOILS: CALIBRATION OF MINIATURE WIND MACHINE  
WITH STANDARDIZED SOILS

Soil Designation (% gravel)	0	1	3.5	7.4	13	23	37.5
Equivalent % clods 0.84 mm (per Chepil)	0	5	12	18.5	25.5	40	60
Soil eroded @ 20 mph air velocity, tons/acre 1 minute 3 minutes 6 minutes	10.1	6.2	7.1	5.0 9.4	3.7 5.1	1.6 3.1	0.23 0.29 0.35
Erodibility Index $I = \frac{X}{X_{60}}$ based on 1 minute erosion time based on 3 minutes erosion time	44	27	31	22	16	7	1
				33	18	11	1

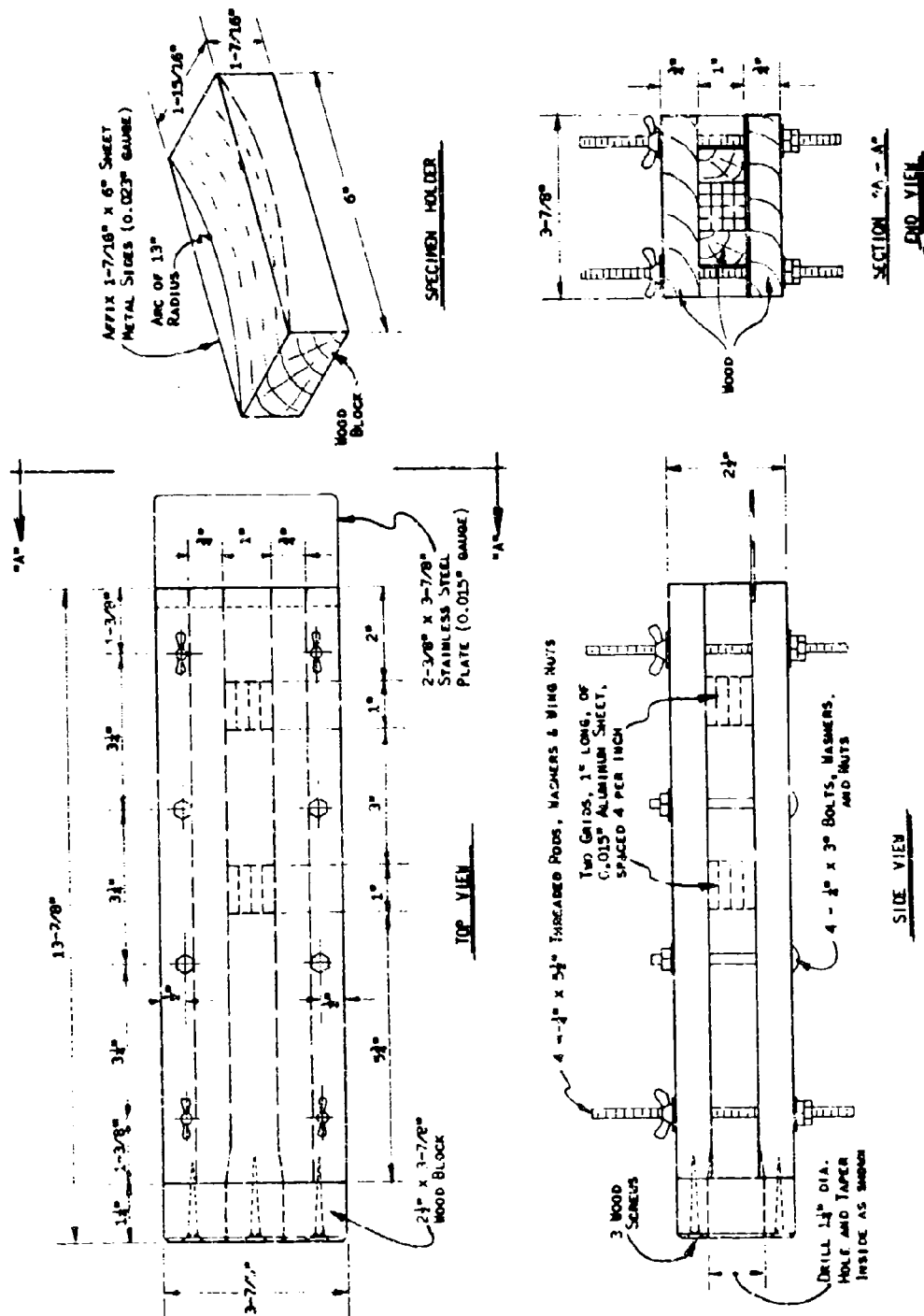


FIG. 1 - AIR DELIVERY TUBE AND SPECIMEN HOLDER  
SKETCHES - NOT TO SCALE

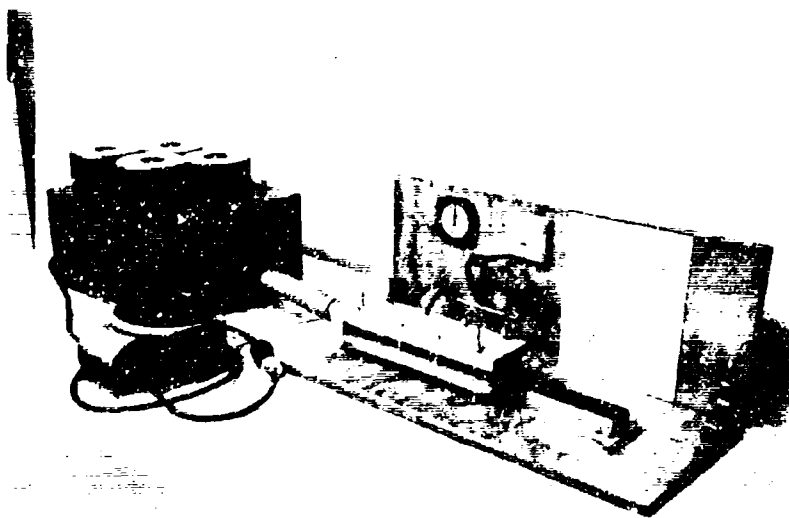


FIGURE 2  
PHOTOGRAPH OF MINIATURE WIND MACHINE

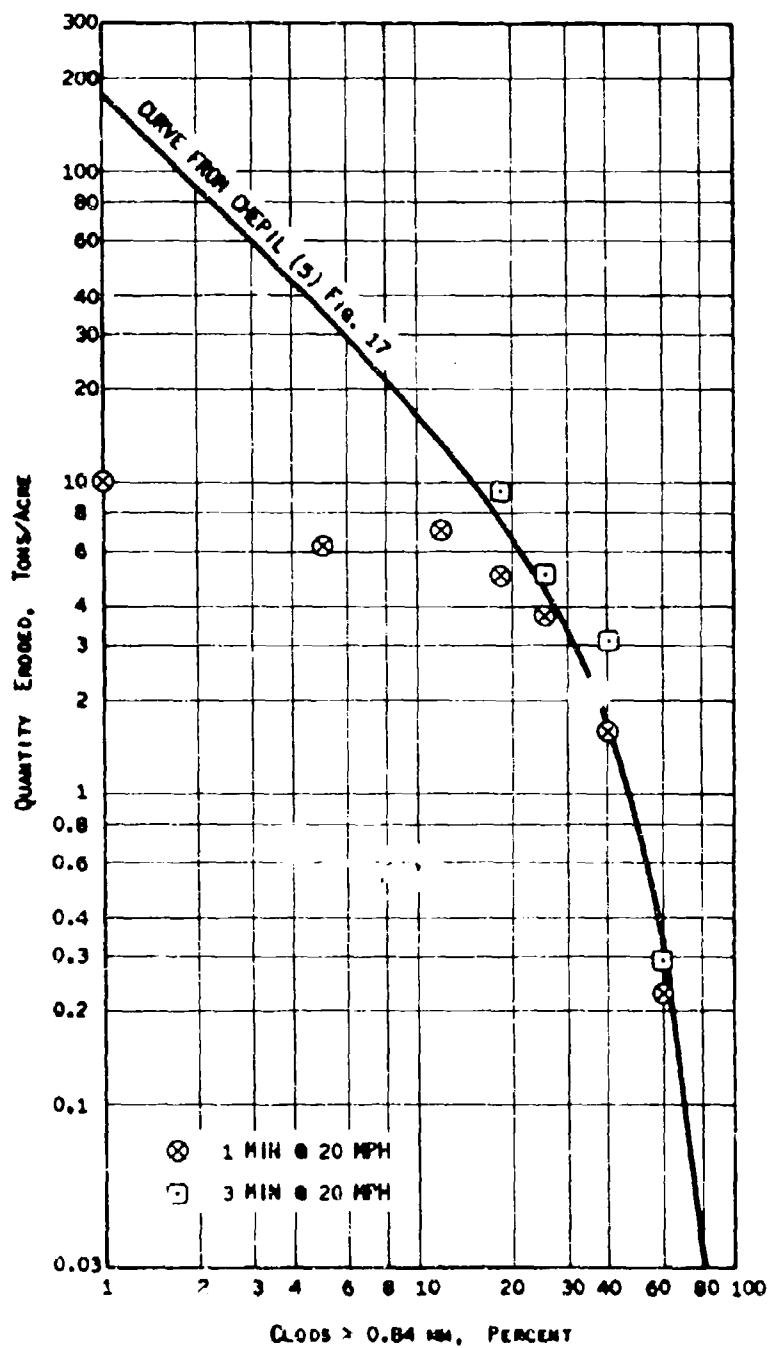


FIG. 3 - EROSION RATE OF STANDARDIZED SOILS WITH MINIATURE WIND MACHINE

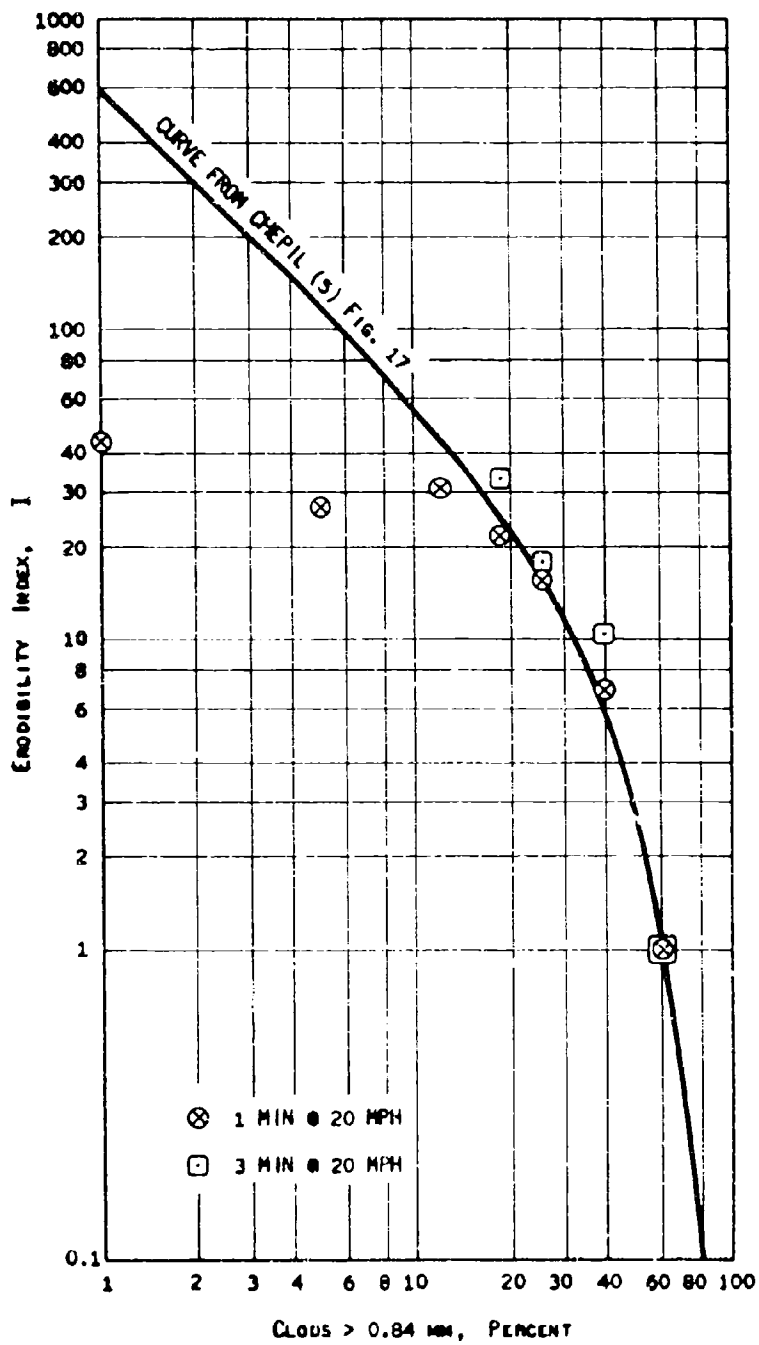


Fig. 4 - ERODIBILITY INDEX DETERMINED WITH MINATURE WIND MACHINE